Phase Rotation Shift Keying for Low Power and High Performance WBAN In-body systems

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***Abstract*—In this paper, we propose a new modulation scheme for low power and high performance WBAN in-body communication systems. Simulation results are presented in terms of performance and transmit power. The proposed modulation scheme is more appropriate for high data rate human body applications than other schemes due to the better characteristic of spectral re-growth in the non-linear system environment as well as better performance.**

Keywords-component; PRSK, PSSK, QPSK, WBAN

I. INTRODUCTION

The study on the Wireless Body Area Networks (WBAN) recently has been concentrated. It supports data rates of several kbps to tens of Mbps according to application usages within 3m. The WBAN systems can be categorized by their applications as an in-body and an on-body system. The in-body systems which interconnect the implanted apparatus in the human body and the apparatus sticking on the human body support a wide range of implant medical applications. The on-body systems serve a various applications between the devices on or around the human body including medical, consumer electronics, personal entertainment and so on. The one of the special features that the WBAN is distinguished from other existing wireless communication technologies such as WPAN, WLAN is the point that it considers the IT-BT (Information Technology - Bio Technology) convergent applications [1].

Especially in the WBAN in-body communication technologies, there are critical issues to be considered seriously different to other wireless communication systems. The first thing is that the implanted systems must be operated with very low power consumption because it might be with a small sized battery and inside the body it should be persisted for a longer time and the battery might be not easy to change. The second is about increasing data rates of the systems. The commercially available capsule wireless endoscopy technologies support 2~3 Mbps data rates. However, the medical applications do not meet the important requirement for high resolution images because they suffer from low resolution and severe distortion of images when physicians zoom in for the detailed diagnosis. The modern wired endoscopes are equipped with high-definition CCD (charge-coupled device) cameras providing up to 30 frame rates at 1920×1080 pixels per frame. However, the conventional wireless endoscopes have no choice but to support a narrow band transmission due to the severe channel conditions and the high power consumption. In the human body, unlike propagation channels of the air, the transmitted signals undergo severe degradations because of the attenuation from various tissues and organs [2]. Low resolution images could result in unintentional oversight of some important spots that may become infected from a disease. Accordingly, it is essential to select a proper modulation scheme providing the stable performance in the human body channel. The miniaturization is the last issue. The implant applications such as a capsule endoscope should be as small as possible because it would be swallowed into the mouth and go out through the internal organs. Consequently, the functions of low-power, high data rate and small form factor are highly demanded for implant medical high data rate imaging applications, such as the future wireless endoscopy technologies.

This paper is on a new modulation scheme for WBAN in-body communication systems. It begins with review of conventional modulation techniques with explaining backgrounds and related theories. In section 3, the new scheme for phase rotation shift keying has been described to understand the concept. Simulations are presented in terms of performance and transmit power and lastly conclusions are given in section 4.

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II. CONVENTIONAL TECHNIQUES

In the conventional implantable wireless devices, the low power modulation techniques have been chosen for a few Mbps data transmission. The characteristic of low-power is the key issue since they must be operated at least for several hours with small-sized batteries. Therefore, low power consumption has been a higher priority issue to decide a modulation technique for WBAN in-body applications. However, in the high data rate applications, it is highly required to choose a high sensitivity modulation and demodulation approach in order to overcome serious attenuation in the human body channel [2].

In a coherent system, binary phase shift keying (BPSK) is 3 dB better than the performance of frequency shift keying (FSK) and on-off keying (OOK). In other words, BPSK systems may transmit 3 dB less power than FSK or OOK at the same performance. However, the BPSK transmitter needs generally back-off power margins to maintain the linearity of a power amplifier (PA) for the high power transmission. It causes to make PA more complex and high power burned. For this reason, according to applications, there are the cases the FSK or OOK is better than BPSK if we consider the low power applications [3]. Nevertheless the OOK and FSK systems have a weak point of low spectral efficiency. The Gaussian filtered FSK can improve the spectral efficiency. However, they also lack link margin for the high data rate applications that provide speed of 20Mbps enabling high-definition image streaming [4].

In terms of spectral efficiency, phase shift keying (PSK) could be the best choice, but a transmitter of PSK needs more transmit power to eliminate significant non-linear distortion of the transmitted signal. The PPM (pulse position modulation) is good alternative for low power consumption for which symbol signals have zero- or silence-envelope. However, it still has drawback that has poor bandwidth efficiency and it is not appropriate for the high data rate in-body communications.

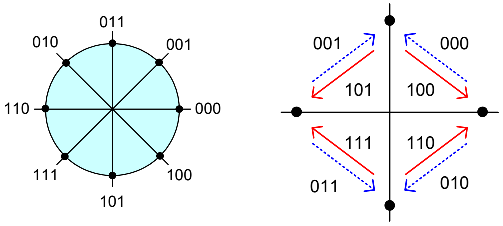
The PSSK (phase silence shift keying) is the modulation compromises between power efficient and bandwidth efficient modulation. The PSSK can achieve better performance at the same average transmit power than the QPSK modulation and it is more bandwidth efficient than the orthogonal modulations such as PPM, FSK and OOK. In addition, it can increase TX (transmit) power efficiency that transmitter sends a zero-envelop period at each symbol like the PPM [5]-[8]. On the other hand, if we fix the average TX power to be same, the peak power of the transmitted signal more 3 dB increase than the QPSK signals, which mean that the PAR (peak to average ratio) of PSSK is about 3 dB higher than the QPSK. The correlation between PAR and ACP (adjacent channel power) is not as straight forward but generally the higher PAR will cause to burn more power.

From the following chapter, we propose a new modulation scheme called PRSK (phase Rotation shift keying). It has advantages the low power consumption for the WBAN in-body communication systems as well as good performance.

III. SYSTEM MODEL

A. Phase Rotation Shift Keying

The phase Rotation shift keying (PRSK) is a kind of phase shift key schemes, However, in the case of M-ary PRSK, the one bit of the information bits determines the transition of phase and ($\log_2$ M-1) bits determine the phase of the symbol. A Comparison of signal point constellations for M = 8 is illustrated in figure 1. For M-ary phase modulation, $M = 2^k$, where k is the number of information bits per transmitted symbol. For the 8-PSK, the range of the carrier phase is $0 \le \theta < 2\pi$, the carrier phases are $\theta_m = 2\pi m/M$ ($m = 0,1,\ldots,M-1$). In the case of 8-ary PRSK, if the first bit of each of information 3 bits is “0”, the phase of the symbol waveform transits from a real part to an imaginary part.(dashed blue line) If the first bit is “1”, the phase of the symbol waveform transits from an imaginary part to a real part.(solid red line)



(a) 8-PSK (b) 8-PRSK

Figure 1. Constellations of 8-PSK and 8-PRSK

The m-th signal of the M-ary PRSK is represented as

$$S_m(t) = \mathrm{Re}\Big\{\Big[\{A\alpha(t) + B\beta(t)\}\cdot \mathrm{Re}\{\exp(j\theta_m)\} + j\{B\alpha(t) + A\beta(t)\}\cdot \mathrm{Im}\{\exp(j\theta_m)\}\Big]\cdot \exp(j2\pi f_c t)\Big\} \quad (1)$$

$$A = \begin{cases} 1, & 0 \le m \le M/2 - 1 \\ 0, & M/2 \le m \le M - 1 \end{cases}$$

$$\alpha(t) = \frac{4\sqrt{2}\gamma}{\pi\sqrt{T}} \frac{\cos\left[2\pi(1+\gamma)t/T + \frac{\sin[2\pi(1-\gamma)t/T]}{4\gamma t/T}\right]}{(2\gamma t/T)^2 - 1} \quad (2)$$

Where $\mathrm{Re}\{c\}$ means the real part of the complex number c, $\exp[\cdot]$ is the exponential function, f_c is carrier frequency, $\theta_m = 2\pi\,\mathrm{mod}(m, 0.5M)/0.5M$, T is a symbol period, $B = \mathrm{mod}(A,1)$. $\alpha(t)$ is the pulse shaping function having the square root raised-cosine (SRRC) spectrum where γ is the roll-off factor, $\alpha(t) = 1$ at $t = 0$, $\alpha(t) = 0$ at $t = kT/2, k = \pm 1, \pm 2, \ldots$ and $\beta(t) = \alpha(t - 0.5T)$.

B. Performance

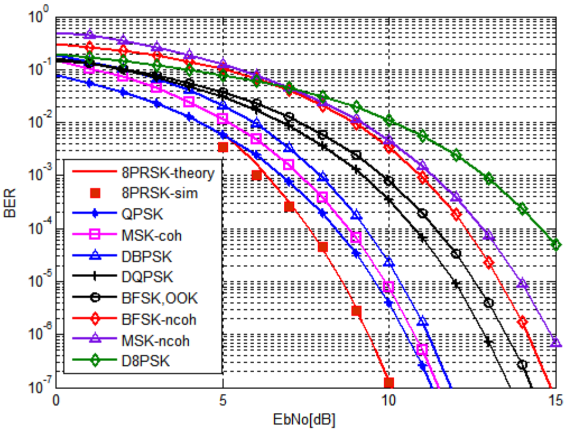
We provide a union bound on P_u for the probability error of PRSK caused by adjacent symbols. P_u can be written as

$$P_u = \sqrt{2E_b/N_0 \log_2 M}\,\sin(2\pi/M), M \ge 8 \tag{3}$$

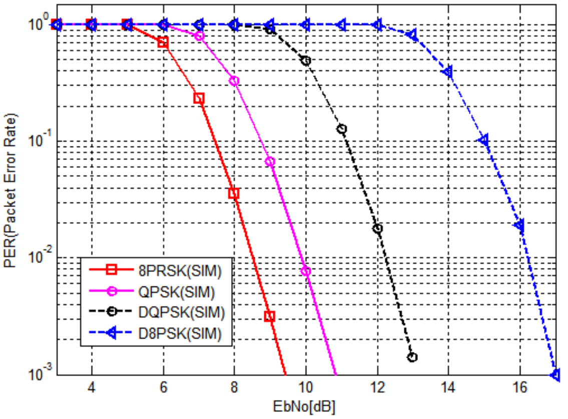
P_u for several M is expressed in the table I.

TABLE I
THE PROBABILITY OF ERROR OF PRSK ACCORDING TO M = 4,8 AND 16

M	4	8	16
P_u	$2Q\sqrt{E_b/N_0}$	$6Q\sqrt{3E_b/N_0}$	$2Q\sqrt{4E_b/N_0}\sin(\pi/8)$



(a) BER



(a) PER

Figure 2. Comparisons of performance

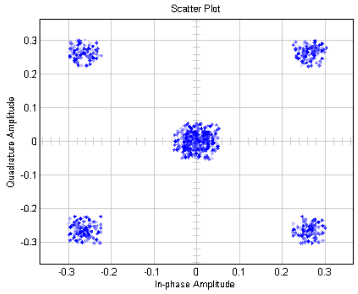
TABLE II
COMPARISONS OF SPECTRAL EFFICIENCY AND PERFORMANCE

Prameter	MSK	GMSK	8PSK	QPSK	PRSK
bps/Hz	0.75	0.88	1.5	1	0.75
BER10^-6	10.5	12.2	14.4	10.5	9.0
Demodulator	Coh	Coh	Coh	Coh	Coh

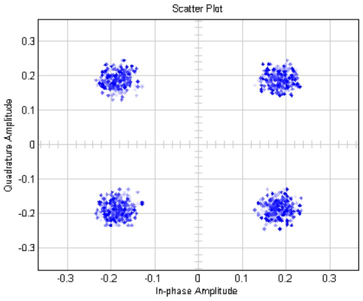
Figure 2 shows the bit error rate (BER) and packet error rate (PER) of 8-PRSK and compares them with the several modulation options. As shown in the figure, 8-PRSK has the best performance of in the modulation options. Comparing to QPSK, the performance of 8-PRSK is superior to 1.3dB. The spectral efficiency of the PRSK is $0.25\log_2 M$ bits/sec/Hz. Table II shows the comparisons of spectrum efficiency of 8-PRSK scheme with other modulation options.

C. Transmit Power

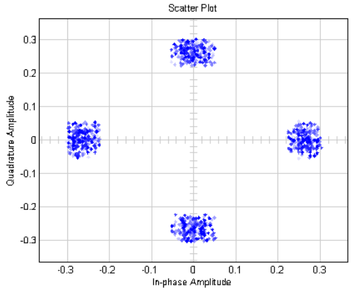
Figure 3 shows the comparisons of the scatter diagrams at the same average transmit power. A square root raised cosine filter with roll off factor (r=1) are used for the transmitter filter. Figure 3(a) shows 8-PSSK transmit signal constellations. Since the 8-PSSK symbols are formed a silence period in every symbol, then the additional constellation point appears necessary in the origin. Accordingly, transition to the origin at each symbol cannot but to make the PAR characteristic of the signals more high. If we fix the average TX power to be same, the peak power of the PSSK signals increase 3 dB than that of the QPSK signals. Figure 3(b) shows QPSK transmit signal constellations. Four constellation points are confirmed in the signal space. Figure 3(c) shows 8-PRSK transmit signal constellations. For every symbol interval, phase of the each symbol rotates by $\pi/2$.



(a) 8-PSSK



(b) QPSK



(c) 8-PRSK

Figure 3. Comparisons of the scatter diagrams

When the higher power a transmitter sends, the higher power consumed exponentially there is. In additional, the power consumption of the power amplifier is generally determined by the peak power of output signal. Therefore, the PAR characteristic has to be applied into the design when the budget calculated for power back-off of the transmit power. In the [9], the back-off value necessary of QPSK was analyzed as about 3.8 dB when the roll-off factor of the SRRC filter was '1'. As like this, it is generally reasonable the PAR value to use for the factor of power back-off margin of the power amplifier. Table III shows the comparisons of PAR values of 8-PRSK scheme with other modulation options. We can observe that using 8-PRSK reduces the necessary back-off and estimate it can save a power gain to 3 dB and 0.8 dB as compared to 8-PSSK and QPSK respectively. Figure 4 show the effects of spectral re-growth of the modulated signals at the same average power and bandwidth. They might be introduced after non-linear devices such as a power amplifier. Low PAR value of PRSK can improve back-off characteristic to reduce the generation of harmonics and the distortion of the signal for non-linearity analog devices.

TABLE III
SIMULATED PAR FOR SRRC ENVELOPE

Modulations	8-PSSK	QPSK	8-PRSK
PAR(dB)	7.68	5.42	4.60

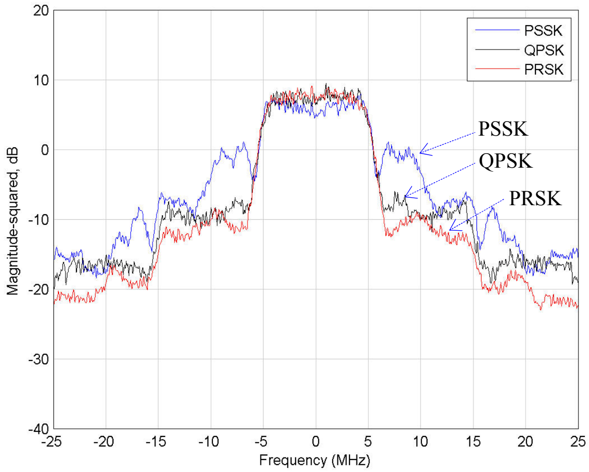


Figure 4. The effects of spectrum re-growth
[Operating frequency is 915 MHz, IP3 : 40 dBm, P1dB : 25 dBm, SRRC (100% roll off) envelope]

D. *Structure of 8-PRSK transceiver*

The block diagram of the 8-PRSK modulator is shown in Fig. 5(a). Information sequence is grouped by 3-bit $\{a_{3n}, a_{3n+1}, a_{3n+2}\}$ one symbol after a serial-to-parallel converter. The first bit of the 3-bit stream decides the direction of transition. At first, the second and third two bits $\{a_{3n+1}, a_{3n+2}\}$ of the symbol are mapped into the 4=2^k possible phase with gray encoding as in the table IV. Further, in the case in which the first bit of each of the grouped bits is '0', phase of a symbol waveform rotates from a real value to an imaginary value of the encoded phase and in the case in which the first bit of each of the grouped bits is '1', phase of a symbol waveform rotates from an imaginary value to a real value of the encoded phase. The encoded signals are oversampled by a factor of L and be inputted to a shaping filter $p(t)$ with square root raised cosine (SRRC) pulse coefficients.

TABLE IV
GARY MAPPING TABLE

$\{a_{3n+1}, a_{3n+2}\}$	$\{d_n\}$	Phase $\{\phi_n\}$
00	1+j	π/4
00	-1+j	3π/4
00	1-j	7π/4
00	-1-j	5π/4

The baseband signals are D/A converted and fed into a quadrature modulator. The waveform of the transmitted 8-PRSK signals s expressed as

$$s(t) = \sqrt{2E_b}\sum_k d_k p(t - kT_s/2) \qquad (4)$$

Where, is the energy per bit and the received signal at the receiver can be expressed as

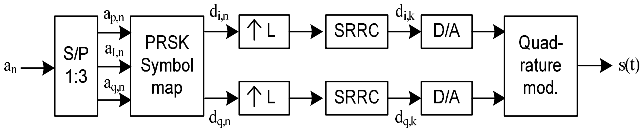
$$r(t) = e^{j\vartheta(t)} s(t-\tau) + n(t) \qquad (5)$$

Where $\vartheta(t)$ represents the composite phase signal of the local oscillator impairments and $n(t)$ is a complex-valued Gaussian white noise process with two-sided power spectral density $N_0/2$. The received signal $r(t)$ is passed through a matched filter of which have the same filter coefficients. The waveform is then sampled to generate the discrete time sequence r_k at synchronized timing instants. Under the assumption of ideal clock recovery, inter symbol interference (ISI) is removed at every $T_s/2$ sample times. In the cross energy comparator (CEC), the first sampled signal and the second sampled signal in each symbol are switched by a real part and an imaginary part and combined each other as following equation (6).

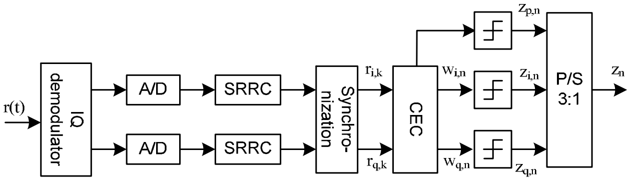
$$\left.\begin{array}{l} r_{2n} = \mathrm{Re}\{r_{2k}\} + j\,\mathrm{Im}\{r_{2k+1}\} \\ r_{2n+1} = \mathrm{Re}\{r_{2k+1}\} + j\,\mathrm{Im}\{r_{2k}\} \end{array}\right\} \quad k = 0,1,2,\cdots K-1 \qquad (6)$$

The magnitudes of the cross combined signals are compared between the first complex value and the second complex value. Then according to which value of signals is larger, the first bit is decoded whether '0' or '1'. Comparing the magnitude of the even-numbered samples and the magnitude of the odd-numbered samples can include determining a first bit of the 3 bits to be 1 when the magnitude of the even-numbered symbol is smaller than or equal to the magnitude of the odd-numbered symbol, and determining the first bit of the 3 bits to be 0 when the magnitude of the even-numbered symbol is greater than the magnitude of the odd-numbered symbol. It can be expressed using the following equation (7).

$$z_{p,n} = \begin{cases} 1 & ,\left|r_{2n}\right| \le \left|r_{2n+1}\right| \\ 0 & ,\left|r_{2n}\right| > \left|r_{2n+1}\right| \end{cases} \quad n = 0,1,2,\cdots N-1 \tag{7}$$



(a) Transmitter



(b) Receiver

Figure 5. The bolck diagram of 8-PRSK trasceiver

Then, the larger signal of the two complex values is chosen for detecting the remaining two bits. It can be expressed using the following equation (8). The results $\left\{w_{i,n}, w_{q,n}\right\}$ finally is decoded in accordance with a decoding table, such as that shown in the table V, and the signal detectors output respective decoded signals $z_{i,n}$ and $z_{q,n}$.

$$w_n = \begin{cases} r_{2n+1} & ,\left|r_{2n}\right| \le \left|r_{2n+1}\right| \\ r_{2n} & ,\left|r_{2n}\right| > \left|r_{2n+1}\right| \end{cases} \tag{8}$$

In the channel model of CM2[2], the analysis on link budget of WBAN in-body channel can be analyzed. Table VI shows that 8-PRSK systems will have the enough link margin and to implement in the human body channel environment.

TABLE V
GARY DECODING TABLE

$\left\{w_{i,n}, w_{q,n}\right\}$	$\left\{z_{i,n}, z_{q,n}\right\}$
+,+	00
+,-	10
-,+	01
-,-	11

TABLE VI
LINK BUDGET ANALYSIS FOR WBAN IN-BODY SYSTEM

No	Parameters	Unit	8PRSK
1)	Bit rate [R]	Mbps	10
2)	Channel Bandwidth [BW]	MHz	13.3
3)	Symbol Period [Tb]	nS	300
4)	In-body Deep Tissue Distance [di]	cm	10
5)	Peak TX Power [Pt_peak]	dBm	0.00
6)	PAR [Pt_peak - Pt_avg]	dB	2.88
7)	Avg. TX Power [Pt_avg]	dBm	-2.88
8)	TX Antenna Gain [Gt]	dBi	-5.0
9)	Center Freuqncy [fc]	MHz	300
10)	Path Loss for CM2 (Deep tissue) [PLi]	dB	60.0
11)	RX Antenna Gain [Gr]	dBi	0.0
12)	RX Power [Pr=Pt_avg+Gt+Gr-PLi]	dBm	-67.8
13)	Avg. Noise Floor [N=-174+10log(BW)]	dBm	-102.8
14)	RF Noise Figure [Nf]	dB	7.0
15)	Total Noise Power [Pn=N+Nf]	dBm	-95.8
16)	Minimum EbNo for Video [EN]	dB	9.3
17)	Minimum SNR [S=EbNo+10log10(k)]	dB	11.1
18)	Implementation Loss [I]	dB	3.0
19)	Link Margin [LM=Pr-Pn-S-I]	dB	13.8
20)	Min. Rx Sensitivity [Pmin]	dBm	-81.7

IV. CONCLUSIONS

In this paper, a new PRSK modulation approach, for the high data rate WBAN in-body systems, has been presented and compared with other modulation options. Compared with QPSK approach, 8-PRSK scheme can achieve 1.3 dB gains in terms of performance and 0.8 dB power back-off gains in terms of transmit power. In addition, it can realize through simple transceiver architecture.

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