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A New Low-Power Noncoherent BPSK Demodulator for Biomedical Applications

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Abstract—**A new non-coherent BPSK demodulator is presented for biomedical implants. This demodulator has simplicity and low-power consumption. The data are recognized based on phase transitions of modulated signal that are equal to rising and falling edge of the digital base-band data. The demodulator works by differentiating the modulated signal three times to produce sharp pulses with adequate amplitude at every 180 phase transition. After this process, the pulses are converted and amplified in current domain then fed as a voltage to a digital level recognition circuit for recovery of initial data. This circuit is designed in a 0.18-µm standard CMOS technology and consumes 55µA @ 1.8V at a data rate of 1 Mbps and carrier frequency of 1MHz. The layout area of the proposed demodulator is about 266µm×80µm.**

I. INTRODUCTION

Nowadays, with improving medical and engineering sciences, the subject of implantable devices in vivo has become more important. These devices are useful for treatment of some disabilities such as deafness and blindness and also some tribulation in neurotic system [1]. Since the implanted microchip may interface with nervous system, it should be able to provide a high data rate [2], [3]. As shown in Fig.1, most of the implantable biomedical system comprises three main parts: external controller, inductive link and an implant device [4]. According to this figure, beside data acquisition, the implanted microchip gains its power by rectifying the carrier of received signal. The amplitude of the received signal defines the amount of the power where the chip acquires.

The three main methods for transferring a digital data to an implant module are Binary Amplitude Shift Keying (BASK) [5], [6], Binary Frequency Shift Keying (BFSK) [7], [8] and Binary Phase Shift Keying modulation (BPSK) [9], [10]. Although BASK is the most simple modulation scheme, the main disadvantage is that the noise influences the amplitude easily [1], [12]. In addition, since the carrier amplitude varies with data, the transmitted power efficiency as well as data transmission rate is nominally low [11]. BFSK and BPSK alleviate this problem, but BFSK modulation is useful for wideband applications where the bandwidth efficiency is not important [11]. Moreover, this modulation needs two carrier frequencies [4] which increase system complexity. Consequently, BPSK modulation is suitable for narrowband applications and has a lower bit error rate (BER) [10] among other modulation schemes. In this modulation, since the carrier amplitude does not vary with data [4], a higher power transferring efficiency can be achieved.

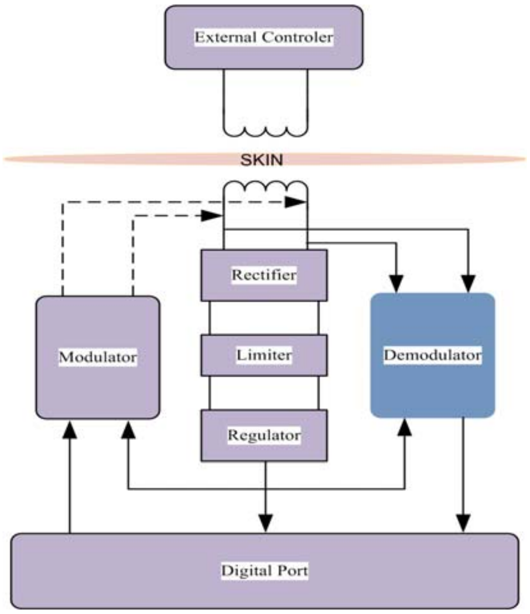

Figure 1. Power and data telemetery for implantable biomedical devices

BPSK demodulators can be divided into two categories; coherent and non-coherent detectors. Coherent detectors [13] are based on phase locked loops (PLL) and usually yield better bit error rate (BER). In the other hand, non-coherent detectors usually try to detect phase discontinuities in the carrier signal. Non-coherent detectors are simpler to design and consume less power.

II. PROPOSED BPSK DEMODULATOR

Figure 2 shows the block diagram of the proposed demodulator. First the BPSK signal enters to a three stage differentiator circuit. This circuit specifies the place of phase transitions of BPSK signal with positive and negative sharp pulses (called hereafter impulses) depending on rising or falling data edges [14]. For further amplification, a current mode amplifier amplifies the impulses in order to be distinguishable by a digital impulse to pulse converter. The following sections

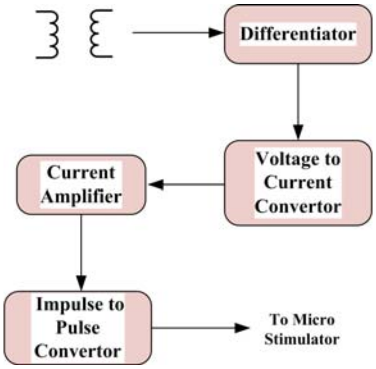

Figure 2. Block diagram of the proposed BPSK demodulator

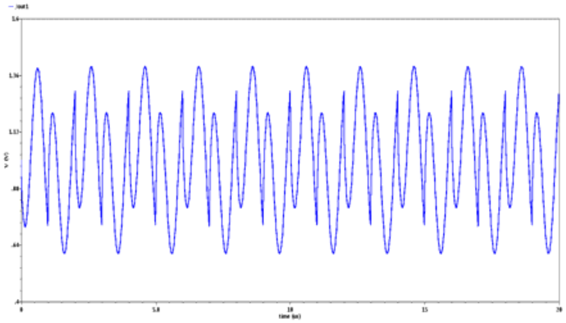

Figure 3. First derivetive of the BPSK signal

describe the operation and circuit detail of each parts of the proposed demodulator.

A. *Differentiator Circuit*

A modulated BPSK signal can be generated ideally by multiplying a bi-polar bit stream, which switches instantaneously between +1 and -1, into a sinusoidal carrier. However, in reality, the transitions in the bit stream are not abrupt and each transition can be best modeled [14] by a hyperbolic tangent (tanh) as

$$bpsk\left(t\right)=\cos\left(\omega t\right)\cdot\tanh(\alpha t)$$

where 2α approximately determine the switching time required by tanhαt.

A differentiator circuit can detect the phase discontinuities in the BPSK signal. However, the bpsk(t) is indeed a continuous signal, so as shown in Fig. 3, a single differentiation operation cannot generate a pulse with adequate height to be detected easily.

$$\begin{aligned}\frac{dbpsk\ (t)}{dt} &= -\omega\sin(\omega t).\tanh(\alpha t)\\ &+\alpha\cos(\omega t).(1-\tanh^2(\alpha t))\end{aligned}$$

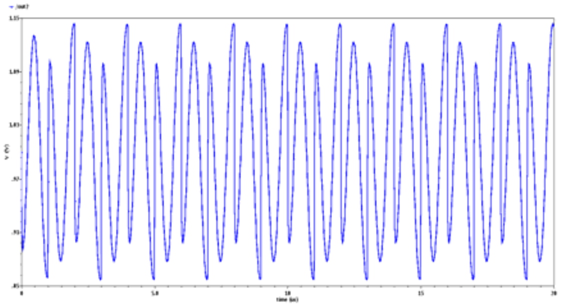

Figure 4. Second derivetive of the BPSK signal

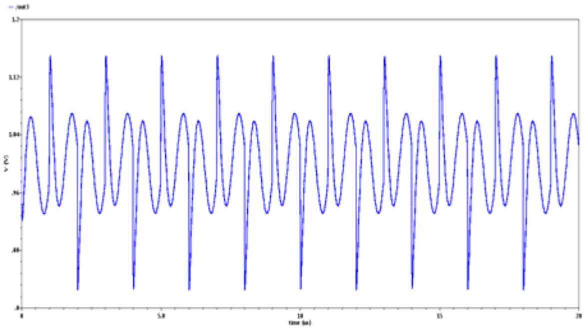

Figure 4. Third derivetive of the BPSK signal

The output voltage of first differentiator at t=0 will be:

$$\left.\frac{dbpsk\ (t)}{dt}\right|_{t=0}=\alpha$$

A second order or third order differentiation can solve this problem yielding impulses with adequate height and decreased carrier amplitude. Showing the result on Fig. 4, the second derivative is

$$\begin{aligned}\frac{d^2bpsk\ (t)}{dt^2} &= -2\alpha\omega\sin(\omega t).(1-\tanh^2(\alpha t))\\ &-\omega^2\cos(\omega t).\tanh(\alpha t)\\ &-2\alpha^2\cos(\omega t).\tanh(\alpha t).(1-\tanh^2(\alpha t))\end{aligned}$$

Accordingly for third differentiator the output voltage at t=0 will be:

$$\begin{aligned}\frac{dbpsk^3(t)}{dt^3} &= -3\alpha\omega^2\cos(\omega t).(1-\tanh^2(\alpha t))\\ &+4\alpha^2\omega\sin(\omega t).\tanh(\alpha t).(1-\tanh^2(\alpha t))\\ &+\omega^3\sin(\omega t).\tanh(\alpha t)\\ &-2\alpha^3\cos(\omega t).(1-\tanh^2(\alpha t))^2\\ &+4\alpha^3\cos(\omega t).\tanh^2(\alpha t).(1-\tanh^2(\alpha t))\end{aligned}$$

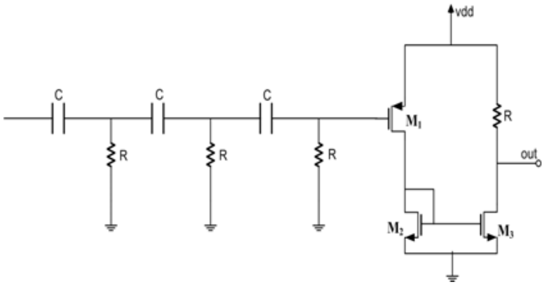

Figure 5. Differentiator,Voltage to Current Convertor and Current Amplifier Circuits

$$\frac{dbpsk^{3}(t)}{dt^{3}}\bigg|_{t=0} = -3\alpha\omega^{2} - 2\alpha^{3}$$

A differentiator circuit can detect the phase discontinuities in the BPSK signal. However, since the slopes of the baseband date are not abrupt, a single differentiator usually produces an impulse with insufficient amplitude. A second or third differentiator can alleviate this problem [14].

Either passive or active differentiators can be used in the demodulator system [14]. the active differentiator consumes more current than the passive one, so as shown in fig.7 in this demodulator the passive differentiator was used.

B. *Voltage to Current Converter*

The amplitude of the impulses generated by the differentiators still may not be large enough to reach the threshold switching voltage of the subsequent digital impulse to voltage converter. In order to achieve a high degree of immunity against noise and process variations, the amplification procedure is performed in current domain. So, a voltage to current converter, implemented by M1 as shown in Fig.7, is used to bring the impulses into the current domain. The conversion gain of the converter is specified by the trans-conductance of M1:

$$i_{sig} = g_{m,M1} v_{sig}$$

C. *Current Amplifier*

The current amplification is performed by a simple current mirror as shown in Fig.7, implemented by M2 and M3. Thus the current gain of the circuit is obtained by

$$A_I = \left(\frac{W_3}{L_3}\right) / \left(\frac{W_2}{L_2}\right) = \frac{W_3}{W_2}$$

The amplified current is then further amplified and converted to voltage by Ro.

D. *Impulse to Pulse Converter*

The voltage at the output of the current amplifier has negative and positive impulses over a DC voltage and a small feed through of the carrier. A technique is needed to convert the impulses to standard digital level pulses without being affected by the DC level voltage and carrier terms. In other words, a windowing mechanism is required to reject intermediate voltage levels, just detecting positive and negative impulses and then restoring the data edges. As shown in Fig.8 The hysteresis window of a Schmitt trigger circuit can be a perfect solution for this problem.

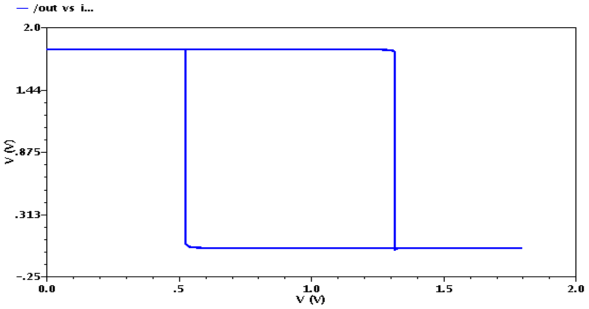

Figure 7. The hysteresis window of a Schmitt trigger circuit

III. SIMULATION RESULTS

In our simulation, we used a multiplier to multiply a pulse (Fig.9) with a sinusoidal signal with frequency of 1MHz, in order to generate a BPSK modulated signal (Fig.10).

The proposed demodulator has been designed in a 0.18-μm CMOS technology. The demodulated BPSK signal is shown in Fig.11. As shown in this Fig the bit transition in output waveform is as same as the input pulse (Fig.9). According to simulation results, the demodulator circuit merely consumes 55μA with the 1.8V power supply at 1 Mbps data rate. As shown in Fig.12 After making the layout of this demodulator

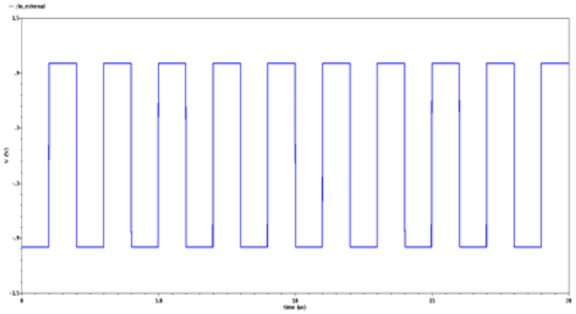

Figure 8. internal Pulse

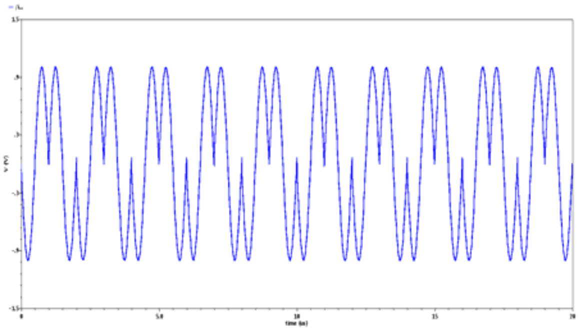

Figure 9. BPSK modulated signal

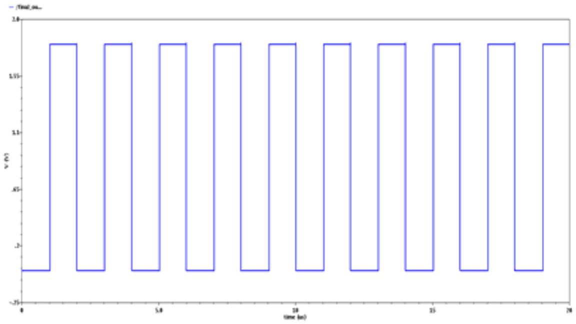

Figure 10. Demodulated BPSK signal

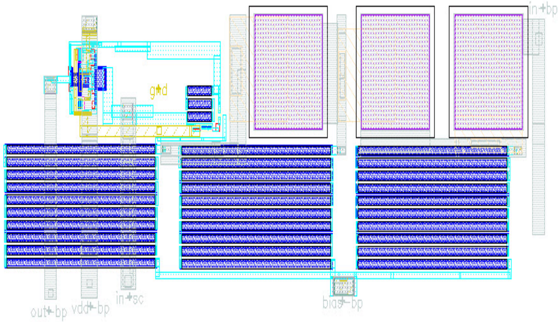

Figure 11. The layout of BPSK demodulator

the dimension of it, is about 266µm*80µm.

We have developed “Figure of Merit” (FOM) to compare this work with other works as:

$$\text{FOM} = \frac{\text{Data rate}}{\text{Power} \times \text{Carrier frequency}}$$

Table 1 shows comparison between this work and recent works briefly. It is clear that this demodulator has a high Data Rate to Carrier Frequency ratio. It means that … . Beside this profit the proposed demodulator has low power consumption, so the FOM of this work is very high in comparison of the other works.

Table 1 Comparison of BPSK Demodulators

Reference	Carrier Frequency (MHZ)	Data Rate (MHZ)	Data Rate to Carrier Frequency Ratio	Power Consumption (µW)	FOM
[9]	10	1.12	11.2%	610	0.18
[10]	8	8	100%	148	6.75
[12]	10	10	100%	119	8.40
[15]	4	0.8	20%	59	4.00
This Work	1	1	100%	110	9.09

IV. CONCLUSUON

In this paper a new low-power non-coherent BPSK demodulator was presented for biomedical implants. This demodulator recognizes the data based on phase transitions of modulated signal that are equal to rising and falling edge of the digital base-band data. Simulation results confirmed the operability of the system. The authors recommend using clock recovery for gaining lower BER, and also using a multi-vibrator before impulse to pulse convertor, whose elongate the sharp pulses, so the impulse to pulse convertor operates better.

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Looking forward to meeting you in Santa Cruz,

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PAPER: ۷۲
TITLE: A New Low-Power Noncoherent BPSK Demodulator for Biomedical Applications
AUTHORS: Bahareh Beheshti, Mohsen Jalali and Mehdi Lotfi Navaii

OVERALL RATING: ۰ (borderline paper)
REVIEWER'S CONFIDENCE: ۲ (medium)

I have non-technical and technical comments on this paper.
۱) In II.B. Voltage-to-Current Converter
"In order to achieve a high degree of immunity against noise and process variations, ~~~~~ is performed in current domain."
=> any references?
۲) Eq. ۸ is simple current mirror, is it safe from noise and process variation?
In ۱) authors mentioned that they selected voltage-to-current converter for good noise and process variations.
۳) Not completed figure ۶. Need to improve. Refer to figure ۵.
۴) Eq. ۹ => need to explain more clearly.
۵) In conclusion, authors said small area is one of feature of this demodulator. Why not include area in FOM equation (Eq. ۹)?
۶) An analysis on how noise will affect performance of e.g. the differentiator should be included.

----------------------- REVIEW ۲ ---------------------
PAPER: ۷۲
TITLE: A New Low-Power Noncoherent BPSK Demodulator for Biomedical Applications

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