A Low-Power Noncoherent BPSK Demodulator for Implantable Medical Devices

B. Beheshti and M. Jalali
Electrical and Computer Engineering Department
Shahed University
Tehran, Iran
bbeheshti@ieee.org

Abstract—A fully-integrated non-coherent BPSK demodulator intended for implantable medical devices is presented. Places of every 180 degrees phase transitions in BPSK modulated signals are recognized using active high-pass filters as negative and positive sharp pulses with adequate amplitude. In order to recover the initial base-band data, the sharp pulses are converted to digital level pulses using an op-amp based Schmitt trigger circuit. For a data rate of 1 Mbps and carrier frequency of 1 MHz, the proposed demodulator achieved a 100% data rate to carrier frequency ratio. Designed in a 0.18 μm standard CMOS technology, it consumes only 49 μA from a 1.8 V supply.

I. INTRODUCTION

In recent decades, relation between engineering and medical sciences such as cooperation in field of implantable devices and microchips in vivo ionize a lot. These devices can be used for therapy of disabilities such as blindness and deafness [1] and also study and treatment of nervous system and its disorders such as epilepsy, paralysis and Parkinson’s disease. As shown in Fig.1, the implant systems receive their power from external controller and have bidirectional data transmission with external world. This communication is provided by wireless technology [2]. Inductive link is the simplest specimen of this technology. The implanted part should gain its power by rectifying the carrier of induced signal, extract the data from received signal and prepare it for stimulation part and also send back information to external world.

In the cases where the implant interfaces with nervous system [3], this device should be capable of providing high data rate [2], [4]. In addition, this device should consume low power and work with a low frequency carrier [5]. There are many methods for transferring a digital data to an implant module, but the three more important of them are Binary Amplitude Shift Keying (BASK) [6], [7], Binary Frequency Shift Keying (BFSK) [8], [9] and Binary Phase Shift Keying modulation (BPSK) [2], [10]. BASK is one of the simplest methods, but since this modulation works by amplitude variation of carrier, a small noise can influence it easily. This causes wrong interpreting of the incoming data, thus increasing the bit error rate (BER) [1], [11]. Moreover, the transmitted power efficiency as well as data transmission rate is nominally low [10], [12]. BFSK and BPSK are more proper modulation schemes, but BFSK uses two carrier frequencies [5], so it is useful for wideband applications that causes poor bandwidths efficiency [8] and increases system complexity. In contrast to BFSK, BPSK has a fixed carrier frequency [11] making it useful for narrowband applications. In addition, it has a relatively high power transferring efficiency and achieves lower bit error rate (BER) among other methods [2].

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

The block diagram of the proposed demodulator is shown in Fig.2. First the BPSK signal enters to a gain stage circuit where its strength is controlled. Then this signal is fed to a two subsequent 2nd order high pass filter circuit. The places of phase transition (bit transition) in BPSK signal are determined with this circuit by generating positive and negative sharp pulses. These pulses are in fact like impulses. Also, this circuit amplifies the amplitude of these impulses making them recognizable for Schmitt trigger circuit. In the next sections, the operation and circuit details of the presented demodulator are described.

A. Gain stage

In implantable microchips, depending on application, the distance between transmitter and receiver coils may vary, causing considerable variation in induced signal strength. In order to guarantee the circuit operability a gain stage circuit should precedes the demodulator. In this design, the gain stage is implemented implicitly within subsequent active high-pass filters.

B. 2nd Order High Pass Filter

By multiplication of a sinusoidal carrier into a bi-polar bit stream, which switches instantaneously between +1 and -1, a modulated BPSK signal will be generated. Of course, in reality, the transitions in the bit stream are not extremely steep and each transition can be modeled [14] by a hyperbolic tangent (tanh) as

$$bpsk \ (t) = \sin(\omega t) \ \tanh(\alpha t)$$

(1)

where a single transition at t=0s is assumed. In this modeling $2\alpha$ roughly specifies the switching time required by $\tanh(\alpha t)$. A high pass filter as a differentiator can detect the phase discontinuities. However, in the BPSK signal there is no discontinuity and a first order differentiation which is defined as

$$\frac{dbpsk \ (t)}{dt} = \omega \cos(\omega t) \ \tanh(\alpha t) + \alpha \omega \ \sin(\omega t) \ \text{sech}^2(\alpha t)$$

(2)

produces a zero at t=0s. So, at least a second order differentiation is needed for specifying these bit transitions. It can be shown that

$$\left. \frac{dbpsk \ (t)}{dt^2} \right|_{t=0} = 2\alpha \omega$$

(3)

But, as shown in Fig. 3(a) the amplitude of these impulses is not adequate enough to being detected in next stage. So, we used another second order differentiation stage to solve this problem as we have

$$\left. \frac{dbpsk \ (t)}{dt^4} \right|_{t=0} = -\alpha \omega (\omega^2 + 3\alpha \omega^2 + 8\alpha^2)$$

(4)

which has a higher value prone to be well recognized by a threshold detector (Fig. 3(b)).

A simple RC passive high pass filter can be used as a differentiator. However, this simple circuit doesn’t amplify incoming signal and thus requiring explicit amplification stage. Active high pass filter, on the other hand, can solve this...
C. Schmitt Trigger

The voltage at the output of the active high pass filters has negative and positive impulses over a DC voltage and a small feed through of the carrier. A technique is needed to convert these 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. The hysteresis window of a Schmitt trigger circuit can be a perfect solution for this problem. Thus, we have used a standard CMOS Schmitt trigger circuit with adjusted hysteresis edges to convert the impulses and restoring the data edges perfectly.

Figure 5 depicts the circuit schematic of the op-amp based embedded Schmitt trigger circuit. In this circuit when $V_{in}$ is low $V_{out}$ is high and $M_1$ bypasses $R_3$. Thus the upper edge of hysteresis window denoted by $v_{in+}$ in Fig. 5(b) is

$$v_{in+} = \left(1 + \frac{R_1}{R_2}\right)V_{ref}$$

while for the lower edge of the hysteresis window, $v_{in-}$ we have

$$v_{in-} = \left(1 + \frac{R_1}{R_2 + R_3}\right)V_{ref}$$

As a result the hysteresis window can be properly adjusted, which is less sensitive to PVT variations of course if $V_{ref}$ is.

III. SIMULATION RESULTS

The proposed demodulator has been designed and simulated in a standard 0.18-μm CMOS technology. The response of the circuit to a BPSK modulated signal is shown in Fig. 6. According to this figure, the circuit can achieve a data-rate-to-carrier-frequency-ratio of about 100%. For a data-rate of 1Mbps and a carrier frequency of 1MHz, the demodulator only consumes 49μA under a 1.8V power supply. A “Figure of Merit” (FOM) has been developed to fairly compare this work with recently published literatures as:

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

Table I summarizes the comparison. Due to a high data-rate-to-carrier-frequency-ratio and relatively low power consumption, the FOM of this work is very high in comparison to the other works.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Carrier Frequency (MHz)</th>
<th>Data Rate (MHz)</th>
<th>Data Rate to Carrier Frequency Ratio</th>
<th>Power Consumption (μW)</th>
<th>FOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>[2]</td>
<td>8</td>
<td>8</td>
<td>100%</td>
<td>148</td>
<td>6.75</td>
</tr>
<tr>
<td>[2]</td>
<td>4</td>
<td>4</td>
<td>100%</td>
<td>93</td>
<td>10.75</td>
</tr>
<tr>
<td>[5]</td>
<td>10</td>
<td>10</td>
<td>100%</td>
<td>232</td>
<td>4.31</td>
</tr>
<tr>
<td>[10]</td>
<td>10</td>
<td>1.12</td>
<td>11.2%</td>
<td>610</td>
<td>0.18</td>
</tr>
<tr>
<td>[11]</td>
<td>10</td>
<td>10</td>
<td>100%</td>
<td>119</td>
<td>8.40</td>
</tr>
<tr>
<td>[15]</td>
<td>4</td>
<td>0.8</td>
<td>20%</td>
<td>59</td>
<td>4.00</td>
</tr>
<tr>
<td>This Work</td>
<td>1</td>
<td>1</td>
<td>100%</td>
<td>88.2</td>
<td>11.3</td>
</tr>
</tbody>
</table>
Figure 6. Response of the circuit to a BPSK modulated signal; (a) BPSK signal at the antenna side and (b) recovered data at the output of the demodulator.

IV. CONCLUSION
A new low-power and high-speed fully-integrated non-coherent BPSK demodulator is presented. The proposed demodulator recognizes the data based on detecting places of phase transitions in modulated signal using active high-pass filters. Then an op-amp based Schmitt trigger circuit assigns each phase transition to a rising or falling edge in recovered data, thus recovering the original base-band data.

REFERENCES
ICEDSA ۲۱۰۲] Your paper #۱۰۵۹۳۸۴۲۲ ('A Low-Power Noncoherent BPSK Demodulator for Implantable Medical Devices')

Dear Dr. Mohsen Jalali:

Congratulations - your paper #۱۰۵۹۳۸۴۲۲ ('A Low-Power Noncoherent BPSK Demodulator for Implantable Medical Devices') for ICEDSA ۲۱۰۲ has been accepted with minor revisions and will be presented in the session titled .

The reviews are below or can be found at https://edas.info/showPaper.php?m=۱۰۵۹۳۸۴۲۲.

========== Review ۱ =========

> *** Originality: New or Novel contribution, also consider papers that contributes to development of applications.
Accept (۸)

> *** Technical Contribution: Technical/Scientific Contribution, also consider papers that contributes to development of applications.
Weak Accept (۶)

> *** Significance of Topic: Relating to the theme of the track/symposium, also consider papers that contributes to development of applications.
Accept (۸)

> *** Presentation: Clarity and Organisation of Content
Strong Accept (۱۰)

> *** Familiarity: Define expertise on subject of the paper
Familiar (۴)

> *** Recommendation: Overall view and recommendation
Accept (۸)

> *** Strengths/Weakness: What are the major strength or weakness to accept/reject the paper ? [Be brief.]

Very clear presentation and exposition.
Good references
clear simulated results

> *** Contributions: What are the major issues addressed in the paper? Do you consider them important? Comment on the degree of novelty, creativity and technical depth in the paper.

> *** Detailed comments: Please provide detailed comments that will be helpful to the TPC for assessing the paper, as well as feedback to the authors.

minor suggested corrections:
even if of obvious meaning, consider to explain BPSK
Dear Dr. Mohsen Jalali:

Thank you for registering your paper \( \texttt{1049428652} \) ('A Low-Power Noncoherent BPSK Demodulator for Implantable Medical Devices') to 2012 IEEE International Conference on Electronics Design, Systems and Applications. You still have to upload your manuscript or full paper, using either web upload or ftp.


- Via ftp: You can upload the paper to ftp://ftp.edas.info, using the file name \( \texttt{1049428652} \) (You MUST use the paper number, not some other file name.)

You can see all your submissions and their status at [http://edas.info/](http://edas.info/) using your EDAS user id mjalali@shahed.ac.ir. Please login using your password.

Once you upload your manuscript, you will receive another email confirmation. Confirmations for ftp submissions may take up to one hour since the ftp directory is swept only periodically.

Regards,
Syed Abdul Mutalib Al Junid
Technical Program Chair