An Asynchronous Event-Driven Data Transmitter for Wireless ECG Sensor Nodes

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***Abstract*—This work presents an asynchronous event-driven transmitter for wireless ECG sensors node. Unlike current solutions for ECG monitoring with autonomous wireless sensors, we propose an asynchronous method to transmit data from an ECG front-end, which is designed with a 2-bit level-crossing analog-to-digital converter. The output bits (`UD` and `Change`) of the ADC are first combined using a pulse encoder circuit and then transmitted via a backscattering link in the 402-MHz MICS frequency band. The pulse encoder comprises an inverter delay chain controlled by signal `UD`, thereby setting the duration of the data pulse. The encoder is enabled only when the ADC has digitized the ECG signal, thus reducing the system's overall power consumption. The complete IC is designed in a standard 0.18m CMOS process. Simulation results show that the ECG readout plus pulse encoder consumes 9.1μW for 45k data conversions per second.**

I. INTRODUCTION

Wireless body area networks (WBANs) have gained substantial importance in the last few years as remote monitoring of biomedical signals became very attractive to the electronics industry. Moreover, the possibility to integrate WBANs in the internet of things (IoT) is a good opportunity to facilitate and increase the use of telemedicine.

Most of the available solutions are synchronous systems [1], [2] and make use of wireless biomedical sensor nodes (WBSN) that consume large amounts of power, thus requiring batteries or energy harvesting combined with energy storage devices such as super capacitors and rechargeable batteries. The problem is that the batteries and energy storage devices increase the final cost of the sensor rendering it unsuitable for applications in which the sensor is disposable.

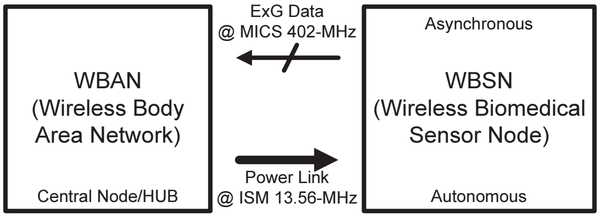

Fig. 1. Block diagram of the proposed WBAN.

An alternative to currently existing solutions is an autonomous WBSN that can sustain itself with energy collected from a remote Radio Frequency (RF) power source without energy storage devices such as super capacitors or rechargeable batteries. Fig. 1 shows this concept applied to a WBAN in which the WBSN collects energy provided by the hub and sends back the information requested. The hub is a central unit that sends power to the WBSN in the 13.56MHz ISM band and processes the data provided by the WBSN. The WBSN monitors vital body signs (e.g. temperature and ECG) and sends the data to the hub through a backscattering link in the 402MHz MICS band. In this work the WBSN is equipped with an ECG readout with a level-crossing ADC and a low-power pulse transmitter. The WBSN only transmits data to the hub when the ECG readout detects a level crossing, which reduces power consumption. Hence, the data transmission is driven by the events generated from the input signal and does not require clock synchronization as it operates asynchronously.

One of the challenges in such a system is that the signal monitoring (analog) front-end needs to provide high resolution data asynchronously. Another challenge is how to transmit the data without pre-processing, storage and synchronization.

In this paper the design and simulation results of an event-driven asynchronous data transmitter combined with a low-power ECG readout are presented. The paper is organized as follows. Section II describes the asynchronous ECG detection interface and data transmission. In Section II-A the ECG detection front-end and back-end are described. Section II-B shows the implementation of the low power asynchronous data transmitter followed by simulation results presented in Section III. Conclusions are drawn in Section IV.

II. ASYNCHRONOUS ECG READOUT AND DATA TRANSMITTER

An asynchronous WBSN can be designed to reduce power consumption. However, the combination of high resolution signal monitoring and realtime data communication is challenging. This section shows the asynchronous ECG readout design and the low-power backscattering based data transmitter.

A. ECG Readout

The proposed ECG readout front-end is an asynchronous event-driven system based on level-crossing sampling [3]–[5]. The block diagram of the front-end is shown in Fig. 2a. The front-end amplifies the weak input voltage signal by the low-noise amplifier (LNA), the voltage-domain signal is then converted into current by the programmable voltage-to-current convertor (PVCC), and the current-mode LC-ADC eventually

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converts the analog signal into two binary representations `Change` and (`UD`). The LC-ADC works similarly to flash ADCs, however conversions are triggered by signal crossings of the reference levels rather than a clock. As shown in Fig. 2b, whenever the input signal crosses a predefined level, the front-end outputs a `Change` pulse to label the crossing and `UD` to denote the level-crossing direction (upward or downward). The 2 binary signals are fed to the low-power wireless transmitter.

B. Low-Power Data Transmitter

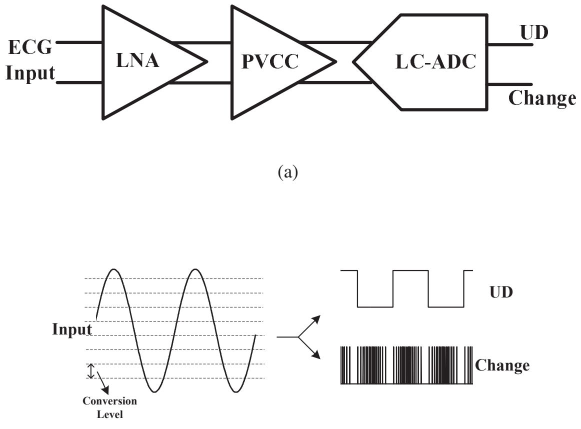
The level-crossing ADC provides 2 binary signals (`Change` and `UD`) that are fed to the low-power data transmitter. As the transmitter is powered by an RF energy harvester [6], to minimize power consumption, the data transmission is only enabled when ADC data conversion is active. The 2 bits provided by the ADC have to be combined and transmitted at once, otherwise information from the ADC is lost. In this paper two methods to encode the ADC data conversion are presented, single pulse mode and multiple pulses mode.

In single pulse mode the 2-bit data stream is combined to generate a pulse with different time duration for upward conversion and downward conversion. This means that the transmitter produces a pulse when `Change` indicates a conversion and `UD` defines the duration of this pulse. In this way 2-bit information can be embedded in a single pulse.

The multiple pulses mode generates a series of pulses when `Change` indicates a conversion. In this case `UD` defines the time duration and number of pulses within one conversion.

The transmitter consists of a digital pulse encoder and a backscattering network. Fig. 3a shows the block diagram of the designed pulse encoder. The pulses are generated by comparing `Change` to `ChangeB`, the later being its complement delayed by six cascaded inverters. The delay time is set by `UD` that makes the pulses longer when it is set to "1". A feedback loop is added to the pulse encoder to implement a 5-stage ring oscillator that is only enabled if `FdbEn` and `Change` are set to "1". The oscillation frequency is defined by `UD` and the capacitor C_D. For `UD` equal to "1" (upward conversion) C_D is connected to ground, thus the pulse width is longer (33ns) and the amount of pulses within one conversion is smaller (6). For `UD` equal to "0" (downward conversion) C_D is disconnected from ground, thus the period of the pulses is shorter (14ns) and the amount of pulses within one conversion is larger (11). This approach might also be used to transmit data with redundancy to improve the bit error rate of the central hub. Fig. 3b shows the waveform of the low-power pulse encoder in two modes of operation.

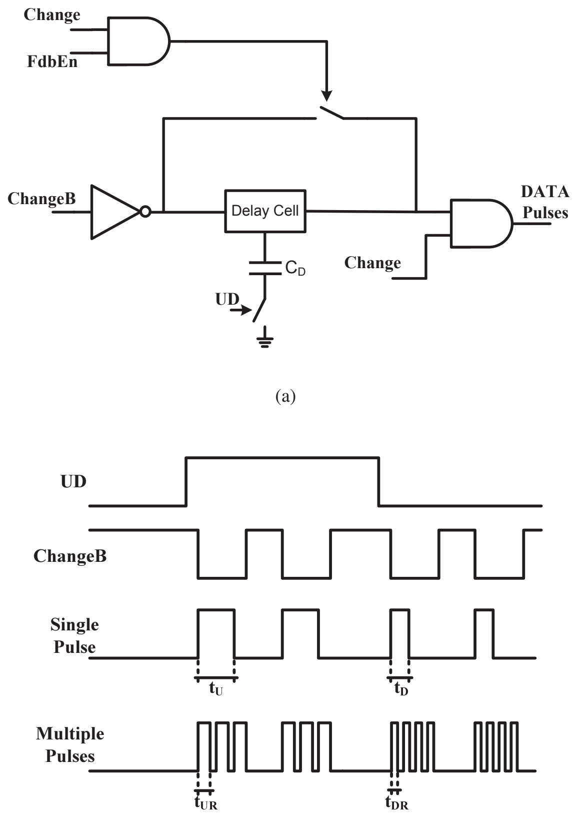
The first mode is single pulse in which the pulse duration equals t_U for upward conversion and t_D for downward conversion. The second mode is multiple pulses with period t_{UR} and t_{DR} corresponding to upward conversion and downward conversion, respectively.



(a)

(b)

Fig. 2. (a) The proposed ECG readout front-end (b) example waveforms for the analog input signal and its 2-bit binary representation.



(a)

(b)

Fig. 3. (a) The block diagram of the low-power data encoder (b) waveforms of the low-power data encoder.

Fig. 4 presents the circuit designed for backscattering data transmission that is controlled by data pulses through transistor M_1. The pulsed signal implements an on-off-keying modulation of the signal received in the LC network.

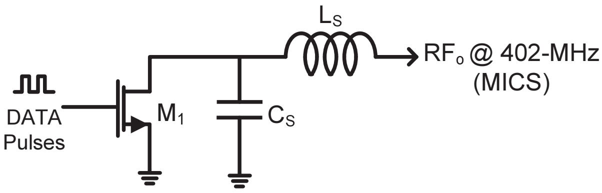


Fig. 4. Circuit diagram of the backscattering data transmitter.

III. SIMULATION RESULTS

This section presents the simulation results of the designed asynchronous low-power data transmitter. To test the designed system, a sinusoidal differential 500Hz 10mV peak-to-peak signal is connected to the input of the ECG readout. The selected frequency corresponds to the highest frequency component of an ECG signal.

Fig. 5 presents the simulation results of the level-crossing ADC and data encoder. The waveforms show both ADC upward and downward conversion indicated by `UD` and `Change`. The encoded pulse is shown in Fig. 6. For every conversion there is only one pulse and the time duration changes with `UD`. The encoded pulses in multiple pulses mode are shown in Fig. 7. The ADC conversion triggers multiple pulses; the pulse width and number of pulses also change with `UD`.

Note that for an input signal at 500Hz the ADC converts 90 times per period, which means 45k conversions are made per second and for this conversion rate the power consumption of the sensor node is 9.1μW . Table I presents a summary of the encoded data for each type of conversion and encoding mode.

Fig. 8 presents the output current of the backscattering transmitter while data is encoded and Fig. 9 shows the power spectral density at the output of the transmitter.

As can be noticed the pulses generate a wide band power spectrum around 402MHz that is 25dB below the power of the carrier. Therefore, and because of the backscattering employed, the transmitter has a power spectral density that does not generate interference to adjacent MICS channels.

TABLE I
SUMMARY OF THE ENCODED DATA

Encoding Mode	**UD**	**Pulse Width**	**No. of Pulses**
Single	0	t_D = 24ns	n.a
Single	1	t_U = 47ns	n.a.
Multiple	0	t_{DR} = 14ns	11
Multiple	1	t_{UR} =33ns	6

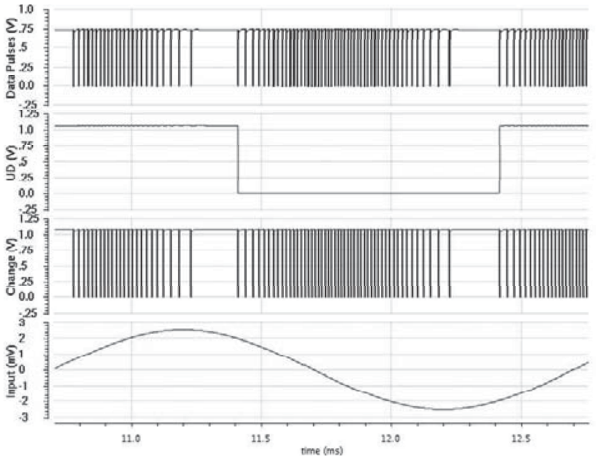


Fig. 5. Simulation results of the level-crossing ADC and data encoder.

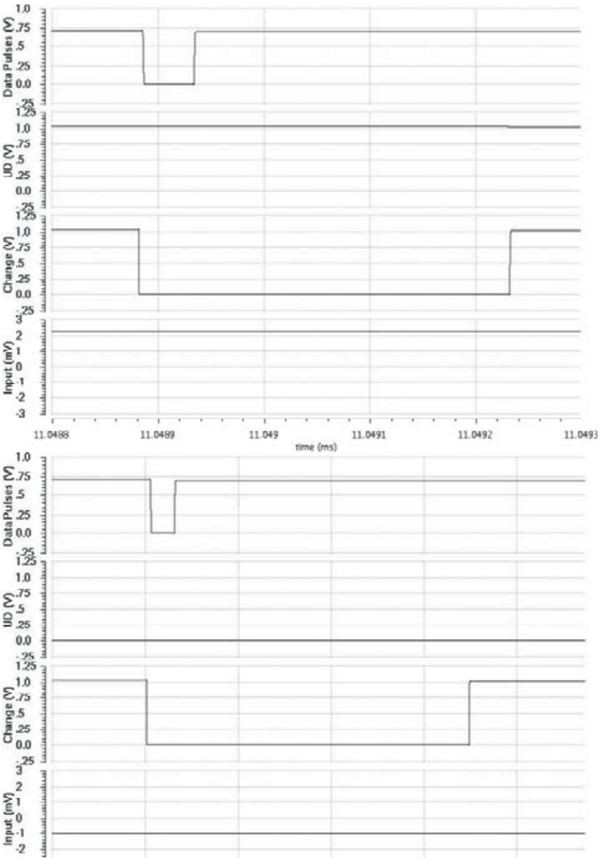


Fig. 6. Simulation results of the data encoder in single pulse mode for `UD` = 1 and `UD` = 0.

IV. CONCLUSIONS

An event-driven asynchronous wireless transmitter for low-power ECG readout applications has been presented in this paper. Unlike current solutions for autonomous wireless sensors with ECG monitoring, this work introduces the concept of an asynchronous way to transmit data that is generated by an ECG front-end. Data transmission based on a backscattering link in the MICS band has been demonstrated. Pulse encoder design operating in single pulse mode or multiple pulses mode has been described and analyzed. The chip is designed to be implemented in AMS 0.18μm process and achieves a power consumption as low as 9.1μW for 45k data conversions per second.

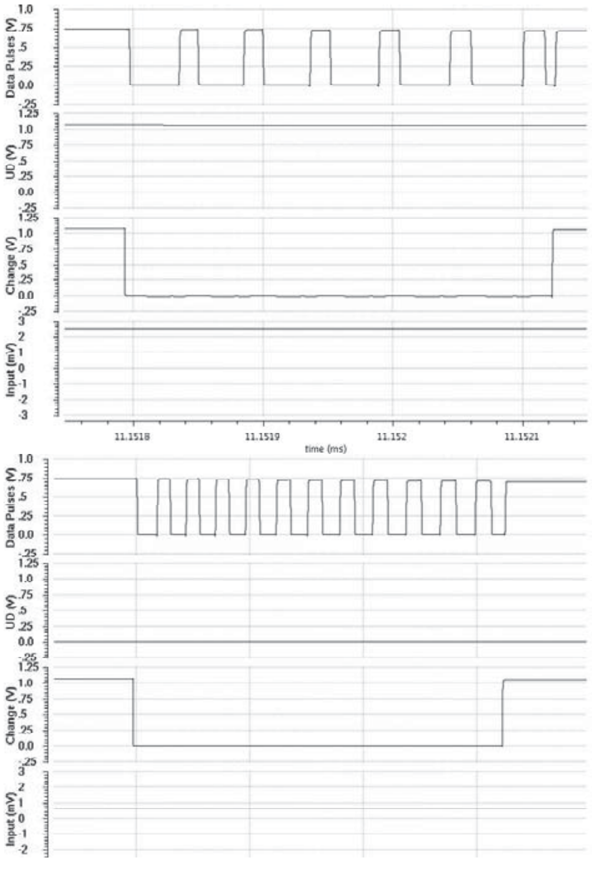


Fig. 7. Simulation results of the data encoder in multiple pulses mode for `UD` = 1 and `UD` = 0.

V. Acknowledgements

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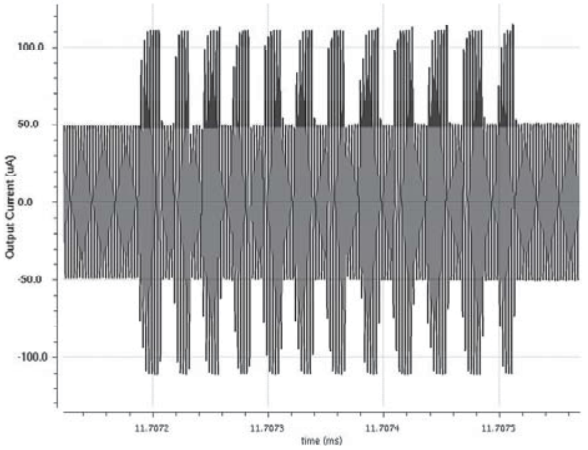

Fig. 8. Simulation results of the backscattering transmitter in multiple pulses mode for `UD` = 0.

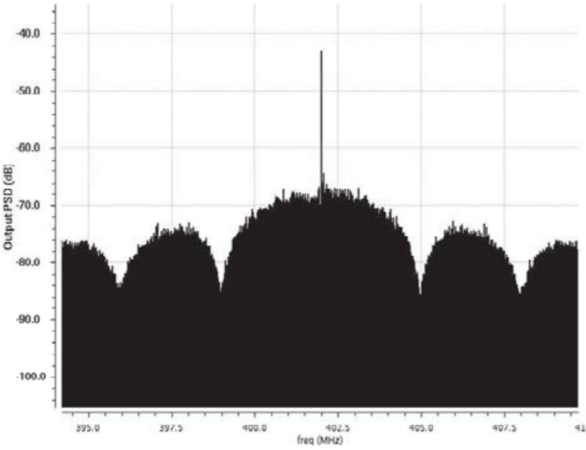

Fig. 9. Simulated Power Spectral Density of the backscattering transmitter in multiple pulses mode.

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