Design of a Low Power Wake-Up Receiver for Wireless Sensor Networks

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***Abstract*—In this work we have implemented a low power wake-up receiver to be used in a Wireless Sensor Networks. On-Off Keying and Pulse Width Modulation are used to modulate and encode the preamble signal. The receiver is composed by an envelope detector with two stage doubler, a data slicer with adaptative threshold, a preamble detector and a PWM decoder with SPI adapter. To improve the receiver sensitivity an LNA, designed using Austria Mikro Systeme 0.35 um BiCMOS technology, has been included at the WUR input.**

***Index Terms*—Wake-up Receiver, Ultra Low Power, Wireless Sensor Networks.**

I. INTRODUCTION

Wireless sensor networks (WSNs) consist of a number of sensor nodes that have the ability to sense the environment, process the sensed data, and disseminate them through a network of distributed nodes. Power consumption is a critical issue in many WSN scenarios where the network is expected to last several months or even years without any external intervention concerning the energy reserves. In order to extend the longevity of the network, many power-saving schemes are used[1].

Typical WSN communication protocols operate in a synchronous or pseudo-synchronous manner to insure that nearby sensors will be awake and able to communicate at the same time. Organizing and maintaining the network's schedule can be a tedious task which may represent a significant drain on the limited energy reserves. On the other hand, using a completely asynchronous mode of operation, where each node can wake up its neighbors to communicate, can lead to very interesting energy savings. Instead of having the network maintain a communication schedule, each node is equipped with a low power wake-up radio (WUR) which monitors the communication channel continuously. When a node wishes to communicate with a neighbor, it sends a wake-up call, containing the wake-up code or address of the target to awake only the desired neighbor. After successful reception and decoding of the wake-up call, the WUR activates the rest of the node if the received code matches one of the node's wake-up codes. An acknowledgement packet is then sent, using the main transceiver, to inform the first node that data transmission can begin. After the transmission, both nodes resume their usual activities and go back to sleep, activating their WUR before doing so [2].

Wake-up radios can be classified into two categories: active and passive. Active wakeup radios consume power as they are listening to the channel continuously, however, they have better wakeup ranges than their passive counterparts due to their higher sensitivity. On the other hand, passive wakeup radios use the energy harvested from the RF signal (or another means of energy harvesting source) and thus operate over shorter ranges. A good wake-up system should switch the main receiver on only if the wake up was intended for this sensor and must integrate conveniently with the rest of the node's electronics. It also should not consume much power for decoding the address and reading the command.

A typical implementation of a dedicated WUR in a wireless sensor device is as an additional circuit to an existing wireless transceiver. The WUR should communicate with the device's microcontroller via some standard interface, and ideally reuse the transceiver's antenna and communication frequency. One example of a typical sensor node with a WUR can be seen in the figure 1.

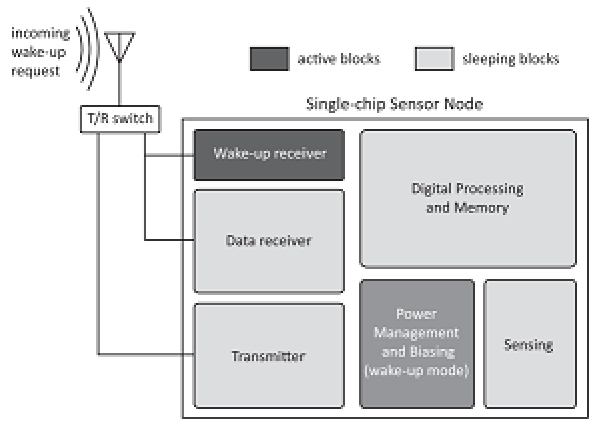

Figure 1. Block diagram of sensor node.

II. DESIGN AND IMPLEMENTATION

The Network Co-ordinator broadcasts a wake-up signal and packet. This signal should be sensed by all sensors in the Network. They read the packet and only the sensor targeted by the wake-up packet turns on its main transceiver. It then either sends a data packet or waits for a certain time to receive additional commands. The wake-up packet consists of a preamble sequence which triggers the wake up event (WUp-Int), followed by a payload which addresses the sensor that needs to be woken up. The packet contains extra commands and instructions. This packet is transmitted using OOK modulation. An Overview of the block diagram presented in this paper can be seen in Fig.2 [3].

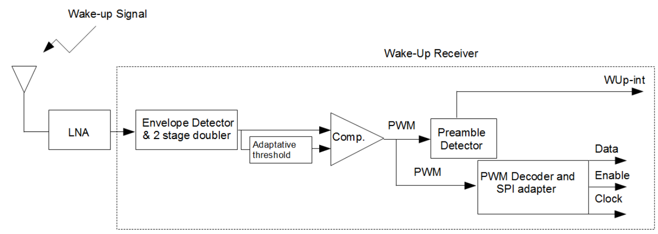

Figure 2. Low Noise Amplifier and Wake-up Receiver Overview.

A Low Noise Amplifier, before the WUR, improves the design sensitivity, a charge pump (two-stage voltage doubler- multiplier) is used as an OOK signal envelope detector. Then, the correct bit sequence for the received packet is formed using the data slicer (comparator). The comparator threshold is adaptive, rather than constant, and it is determined by the strength of the received signal. A Preamble Detector triggers the wake up interrupt if the preamble is in the expected OOK datarate range. The next part of the circuit is the Pulse Width Modulation (PWM) decoder and the Serial Peripheral Interface (SPI) adapter. This part of the circuit first decodes the PWM encoded signal and generates SPI compatible signals for data transfer to the processor.

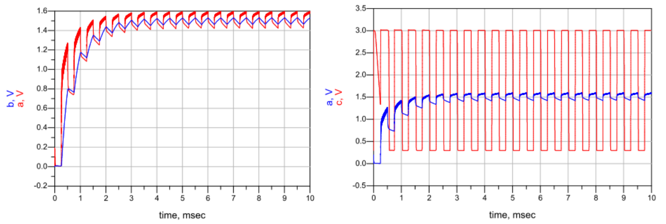

Figure 4. (a) Output from the envelope detector. (b) Adaptive threshold. (c) Output from the comparator, PWM signal.

B. Data Slicer

The next part of the circuit (R1 and C5) is used for adaptive threshold generation (Fig.4, signal ‘b’).[4] The adaptive threshold mechanism has two advantages:

- The threshold value for the comparator is always held at 50% of the ‘a’ signal level, according to received signal power. This is used to increase the dynamic range of the WUR, for both weak and strong signals.
- The energy from the antenna is used for the threshold generation, instead of a voltage divider, therefore static power is reduced.

C. Preamble Detector and Wake Up Signal Generator

The next part of the circuit (R7, C6, C7, DIODE5 and DIODE6) is used to generate a wake up interrupt from the preamble. The preamble is an OOK signal of higher frequency than 2kHz in our implementation (Fig.5).The preamble detector drastically reduces false wake up interrupts caused by spurious wireless transmissions in the vicinity of a WSN.

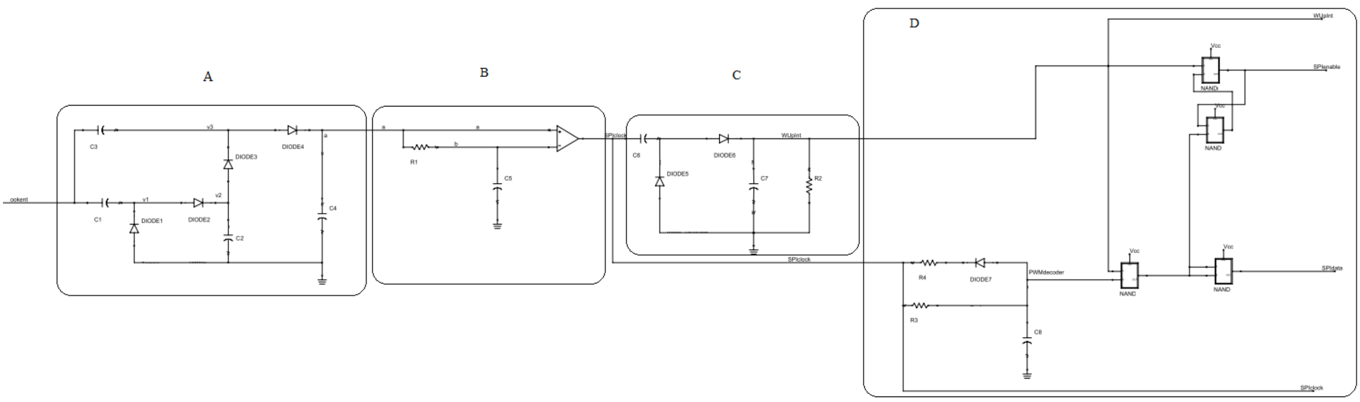

Figure 3. Wake Up Receiver Circuit

A. Voltage Doubler and Envelope Detector

A schematic of the WUR is shown in Fig.3. The first part of the circuit is the voltage doubler (DIODE1, DIODE2, C1 and C2) and the envelope detector (DIODE3, DIODE4, C3 and C4). It extracts the envelope of the received OOK signal. Resulting signal is shown in Fig.4, signal ‘a’.

D. PWM decoder and SPI adapter

The last part of the circuit (R8, R9, C8, DIODE7 and NAND Schmitt trigger) is used to decode the PWM signal and make it SPI compatible. First, the PWM signal is filtered using R3-C8, where only longer pulses (logical “1”) can raise input to the Schmitt “1” level. The rest of the logic is used to generate the SPI data and SPI enable signals. A high level of the WUp signal is needed to generate

SPI data. An SPI enable signal is generated when the first bit in the packet arrives (Fig.6 bottom signal). This bit has to be “1” (start bit). Then, the SPI data is the PWM filtered signal (Fig.6 middle signal), and the SPI clock is the raw PWM signal after the comparator (Fig.6 top signal). The WUR acts as a SPI master.

E. Low Noise Amplifier

At the input of the wake up receiver, we add a low noise amplifier. The main objetive of the LNA is to improve the sensitivity of the wake up receiver designed. We have chosen a resistive feedback LNA.

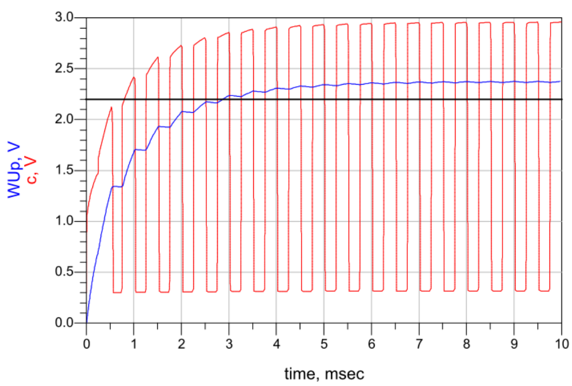

Figure 5. Preamble detector’s input (signal ‘c’) and output (signal ‘WUp’).

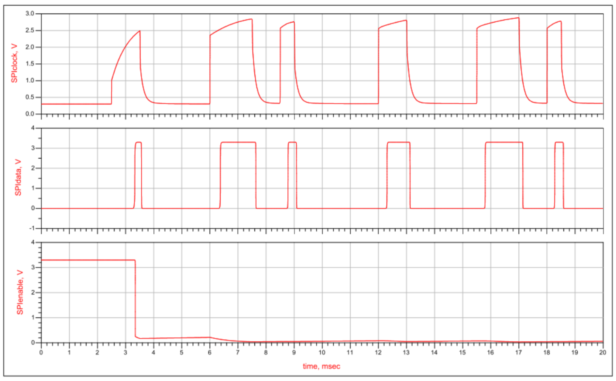

Figure 6. SPI clock, SPI data and SPI enable.

III. CONCLUSION

In this paper we have successfully designed, in the 433.92 MHz band, a low power WUR receiver for WSNs. The WUR is composed by an envelope detector and two stage doubler, a data slicer with adaptative threshold, a preamble detector and a PWM decoder with SPI adapter. To improve the WUR sensitivity, a resistive feedback LNA has been included at the WUR input. With this configuration, the WUR sensitivity has been increased from -28 dBm to -53 dBm with an average current consumption of 1.733 uA. This LNA has been designed using Austria Mikro Systeme 0.35 um BiCMOS technology.

IV. REFERENCES

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