Demo Abstract: A Novel Architecture for Semi-Active Wake-Up Radios Attaining Sensitivity Beyond -70 dBm

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ABSTRACT

In this work we propose a new scheme for semi-active *Wake-Up Receiver* circuits that exhibits remarkable sensitivity beyond *-70 dBm*, while state-of-the-art receivers illustrate sensitivity of up to *-55 dBm*. The receiver employs the typical principle of an envelope detector that harvests RF energy from its antenna, while it employs a nano-power operation amplifier to intensify the obtained signal prior to the final decoding that is realized with the aid of a comparator circuit. It operates at the 868 MHz ISM band using *OOK signals* propagated through LoRa transceivers, while also supporting addressing capabilities in order to awake only the specified network's nodes. The power expenditure of the developed receiver is as low as *580 nA*, remaining at the same power consumption levels as the state-of-the-art implementations.

CCS CONCEPTS

• **Hardware** → **Circuits power issues**; **Sensor devices and platforms**; *Wireless devices*; **Platform power issues**.

KEYWORDS

Wake-Up Receiver, Power Management, Low-power Design, IoT

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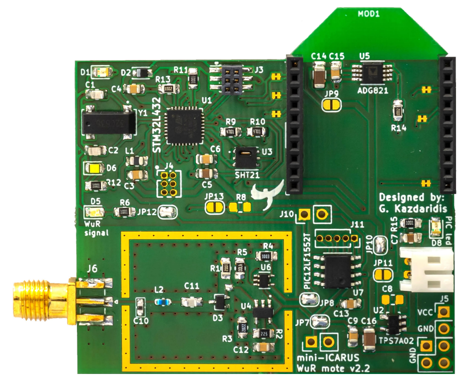

Figure 1: The mini ICARUS mote w/ WuR Receiver

1 INTRODUCTION

Energy efficiency is a leading topic of research in the domain of *Wireless Sensor Networks* (*WSNs*). In most real-world applications, sensor nodes are battery operated, while their life duration is solely dependent on the battery's remaining charge and the node's power profile. A common strategy for saving energy in sensor networks is the *duty-cycle* practice, which suggests that sensor nodes enter a low-power mode, the so-called sleep state, in order to save as much energy as possible during their inactive periods. The sleep state is interrupted by short, burst events, where sensors sense, process and propagate data. The above principle is usually realized using internal or external time keeping circuits that provide fixed interrupt signals to awake the devices from their sleep state [3]. Moreover, it is common that the interval of the wake-up signals is fixed and predefined depending on the application scenario of the network. Despite the fact that the aforementioned principle significantly reduces the overhearing and idle listening problem, which is a major source of energy wastage, it is not considered to be the best practice, especially in application scenarios that do not require fixed time intervals.

Another method that eliminates the duty-cycle obstacle is the employment of a *Wake-Up Receiver* (*WuR*), presented in a few research works [1, 6, 7]. This receiver is actually an auxiliary circuit usually attached to the main sensing device in order to notify the latter to switch from its sleep to its active phase. This circuit typically draws less than *1 μA* in order to remain as energy efficient as possible. Usually, a semi-active *WuR* combines an envelope detector that is a passive circuit along with a low-power comparator circuit

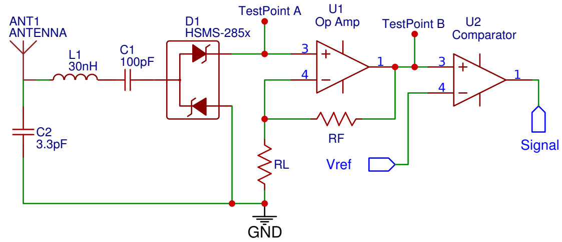

Figure 2: Proposed *WuR* Schematic Circuit

that is an active component. It is worth noting that the best obtained performance in semi-active *WuR* systems in terms of sensitivity is observed in [6] with a reported sensitivity of *-55 dBm*, while the receiver circuit drains *600 nA* when operating in its quiescent state.

In this work we leverage the existing semi-active principle and we introduce a novel enhancement that offers substantially increased sensitivity, that goes beyond *-70 dBm*, while the power consumption of our *WuR* circuit remains at the same levels.

2 WAKE-UP RECEIVER IMPLEMENTATION

The developed prototype receiver consists of low-cost electronics and a low-power micro-controller. The schematic diagram of the receiver is illustrated in Fig. 2, while the *mini ICARUS* mote that integrates the proposed *WuR* circuit in Fig. 1. For the wake-up receiver a matching network, a passive rectifier (*HSMS-285c*), an Operation Amplifier and a Comparator *IC* (Integrated Circuit) were used. Moreover, a low-power micro-controller (*MCU*) is responsible for processing the received signal and identifying the acquired address to verify whether it should wake-up the host node or not. To awake the network's nodes we utilize *868 MHz LoRa* radio transceivers, employing the *On-Off Keying (OOK)* modulation.

Our finding lies in the observation that the power harvested by the envelope detector (*TestPoint A*, in Fig. 1) is not adequate to trigger the next stage when receiving high attenuated wake-up packets. Notably, in all the previously published works the harvested signal by the envelope detector (*HSMS-285c*) in *TestPoint A* is fed directly to the comparator *IC*, thus the overall sensitivity of the *WuR* is solely depended on the characteristics of the comparator being used. When using a comparator with low Input Offset Voltage (V_{OS}), as for example the *LPV7215* (300 μV V_{OS}), the *WuR* circuit achieves high sensitivity of *-55 dBm*, while when employing the *TLV3691* (*3 mV* V_{OS}) the obtained sensitivity is only at *-32 dBm*. Of course, the power consumption of these comparators is proportional to their performance, meaning that the *TLV3691* draws only *110 nA* while the *LPV7215* consumes roughly *580 nA*. In our work we propose a new architecture, by first amplifying the harvested RF signal (*TestPoint A*) and then feeding the intensified signal (*TestPoint B*) to a low-power comparator. Leveraging this strategy we are able to detect RF signals even when receiving highly attenuated packets, thus we achieve sensitivity far beyond the state-of-the-art. Our early experiments have illustrated sensitivity beyond *-70 dBm*. Fig. 3 illustrates the obtained signal level amplified by the operation amplifier as measured in *TestPoint B* with a yellow line, and the output of the comparator *IC* (labeled as *Signal*) with a green line, when receiving a wake-up packet at *-60 dBm*.

The Operation Amplifier we have employed is the *LPV811* that features *450 nA* power draw, configured to amplify the obtained signal a hundredfold. Next the signal is fed to the comparator *IC*,

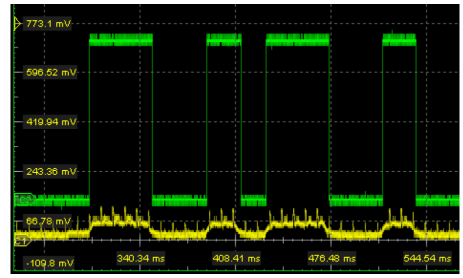

Figure 3: Amplified Signal upon Packet Reception at *-60 dBm* (Yellow line) & Comparator's Output (Green line)

which in our prototype is the *TLV3691* that consumes *110 nA*. We opted for the *TLV3691* in spite of featuring high V_{OS}, since the proposed circuit is no longer dependent on the comparator's V_{OS}. The overall consumption of *560 nA* can be further optimized by reducing the supply voltage from *3.3V* to *1.6V*. Lastly, we note that we utilize the *8-bit PIC12LF1552T* to process the received signals. The *PIC* draws *20 nA* when asleep and roughly *110 µA* at *3.3 V* supply when processing a received frame operating at *2 MHz*. Notably, the host *MCU* of the mini-ICARUS is the *STM32L432* that also draws 20 nA in the sleep state. More technical details can be found in [2].

3 DEMONSTRATION

The demonstration phase consists of three scenarios that showcase address matching, sensitivity, and power consumption respectively. In the first scenario, *LoRA* transceivers are used to transmit address carrying signals aiming to wake specific nodes. In the second scenario, a transmission channel is formed using a variable attenuator in order to evaluate the sensitivity of the proposed *WuR*. In the final scenario, we measure and characterize the power consumption profile of the *WuR* using our power monitoring tools [4, 5].

4 CONCLUSIONS

In this work we showcase a new scheme for semi-active *WuR* circuits that remarkably increases the sensitivity of the existing state-of-the-art implementations, reaching beyond *-70 dBm*. Our finding lies in the employment of a nano-power amplifier that intensifies the signal prior to the decoding process. The overall consumption of our proposed circuit is roughly *580 nA* at 3.3V supply, while it can be substantially reduced by using alternative *ICs*.

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