A SMART RFID Transponder

Riad Kanan
University of Applied Sciences
Rte du Rawyl 47
1950 Sion, Switzerland
riad.kanan@hevs.ch

Darko Petrovic
University of Applied Sciences
Rte du Rawyl 47
1950 Sion, Switzerland
darko.petrovic@hevs.ch

Abstract—**This paper presents a semi-passive universal, multi-applications, SMART RFID Sensing Transponder (SRST). It consists of a new low-power passive 13.56MHz RFID Analogue Front End (AFE), a micro-controller, sensors and rechargeable battery. The AFE was designed and fabricated successfully based on using a 0.35um CMOS technology. To allow re-charging a battery through the RF field, a new RF energy harvesting system is designed and integrated within the AFE; this leads to a self-powered system, which is a new benefit in the RFID sensing and continuous monitoring.**

Keywords-SMART RFID; sensing system; Low-Power.

I. INTRODUCTION

RFID (Radio Frequency Identification) technology has been widely used in the past few years as it helps identify objects and people in a fast, accurate and inexpensive way. It is used into many areas, including product tracing, transportation payment, animal identification, as well as passports, etc. [1].

RFID systems are comprised of three main components: the tag or transponder, the reader or transceiver that reads and writes data to a transponder, and in some applications, the computer containing database and information management software.

RFID tags can be active, passive, or semi-passive. The communication of active RFID is powered by its own battery which enables higher signal strength and extended communication range of up to 100 m. But the implementation of active communication requires larger batteries and more electronic components leading to higher costs. Passive and semi-passive RFID send their data by reflection or modulation of the electromagnetic field that was emitted by the Reader. The typical reading range is between 10cm and 3m.

In recent years, RFID has been introduced in sensing applications and semi-passive RFID tags are mainly used for such applications. The battery of semi-passive RFID is only used to power the sensor and recording logic. New developments have provided solutions for temperature monitoring, but RFID for sensing applications is still limited to sensing and storing the temperature and fulfilling the functionality of data logger [2][3]. Semi-passive RFID loggers offer an economical solution for the spatial profiling of transports with a high number of loggers.

Data loggers are standard tools for the supervision of cool chains. In order to handle the data for a high number of temperature records, the measurements have to be processed locally. It is not feasible to transmit full temperature data by a reader at unloading of a truck or container [4][5].

The shelf life prediction system is an example of application where huge data have to be processed locally. The system used to monitor the changes in quality of perishable foods during the transport phase and record them [5][6]. When addressed, the system delivers the prediction of the remaining shelf life time based on the used keeping quality model which uses the Arrhenius' Law, saying that, all reaction rate constants are assumed to depend on temperature [7][8].

An intelligent RFID sensing transponder has to measure the ambient parameters, process the information locally and transmits only the important information. Currently, there is no RFID transponder with a freely programmable processor. Indeed, the available RFID transponders do not allow the development of new applications because their protocols are already frozen by the chip logic core.

In this paper, a SMART RFID Sensing Transponder system is presented. It includes a new passive RFID chip and a platform which allows the following:

- A freely programmable processor for the development of new applications
- Cost-effective to facilitate the deployment
- The system allows storing the history of the measured environmental condition data (Temperature, Humidity, etc.)
- Layered HW/Firmware/SW system structure which allows a modular structure. The transponder provides an easy update and offers the possibility to extend application domains

Energy consumption of the transponder system has been minimized to a high extent by appropriate design and system control.

 ISBN: 978-1-61208-203-5

In addition, a Smart energy harvesting has been developed to ensure energy autonomy and to allow sensing and continuous monitoring. These represent radical progress in RFID sensing applications.

The paper is organized as follows. In Section II, we describe the proposed transponder system. In Section III, we present the transponder power consumption analysis. Section IV presents the designed Analogue Front End chip. Section V discusses the AFE experimental results. Finally, we present a conclusion of the work in Section IV.

II. RFID SENSING TRANSPONDER SYSTEM

The transponder system (SRST) is a semi-passive element. Figure 1 shows the general architecture of the tag which is designed with the minimum electronics components and optimized to achieve a low current consumption during operating period. The tag is composed of a new passive RFID Analogue Front End (AFE) chip, a micro-controller, EEPROM and sensors.

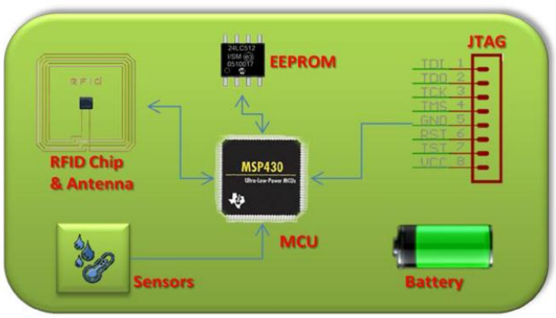

Figure 1 – SMART RFID Sensing Transponder architecture

Figure 2 and Figure 3 show the front and the back view of the realised prototype device for the transponder.

Figure 2 – SMART RFID Sensing Transponder prototype (Front view)

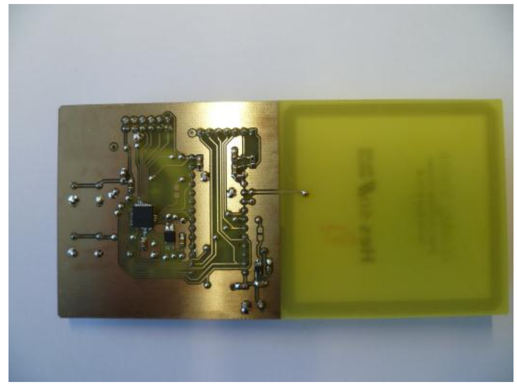

Figure 3 – SMART RFID Sensing Transponder prototype (Back view)

The component list used in the proposed sensing transponder is summarized in Table I. A microcontroller is used to develop applications and process data provided by sensors and stored in an EEPROM. Thanks to the new AFE intended mainly to the communication and energy scavenging, the SRST allows freely programmable processor for the development of new applications.

TABLE I. SLTT COMPONENT LIST

Component	Model	Notes
Microcontroller	MSP430F2350IRHA	16KB Flash, 256KB RAM
Sensor	SHT11	Temp & Humidity
EEPROM	24LC256-I/SM	256KB
Regulator	TPS78233	
AFE	***Proprietary***	***13.56MHz RFID Analogue Front End***

To add sensors to the tag, a microcontroller becomes necessary for the analysis of the measured values. The processor module calculates and stores the resulting values into a programmable memory EEPROM. The stored data are sent when receiving a “data-log” command from the reader. The RFID AFE Chip transmits the stored data over the RF Field to the reader. In addition, the RFID tag sends a real time sensor measures. In this case, the microcontroller sends the measured values of the sensors, after a conversion, directly to the RFID chip. For the programming of the micro-controller and the development of a new application, a JTAG (Joint Test Action Group) interface is added.

III. TRANSPONDER OPTIMIZED POWER CONSUMATION CONSIDERATION

The transponder system is optimized for low-power dissipation in order to extend the battery life, which allows the condition monitoring during the transport for instance. After the good shipment, a new battery charging cycle is started to prepare the transponders for a new shipment.

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Table II summarizes the power consumption of each component of the transponder.

TABLE II. POWER CONSUMPTION SUMMARY

Chip	Active mode	Standby mode
MSP430F2330	390µA @ 3V, 1MHz	1µA @3V
SHT11	550µA @3.3V	0.3µA @3.3V
24LC256	Read=400uA, Write=2mA @3V	5µA @5.5V

Extending the battery lifetime requires an efficient use of the transponder components which must then be turned off when not required. This is what is called the duty-cycling, i.e. the sensor is active during a short period and goes to the standby mode when its sensing information are sent and or stored in the EEPROM. The EEPROM is switched to the standby mode after a write cycle.

Figure 4 presents the current consumption at different operating steps of the transponder during one sampling period.

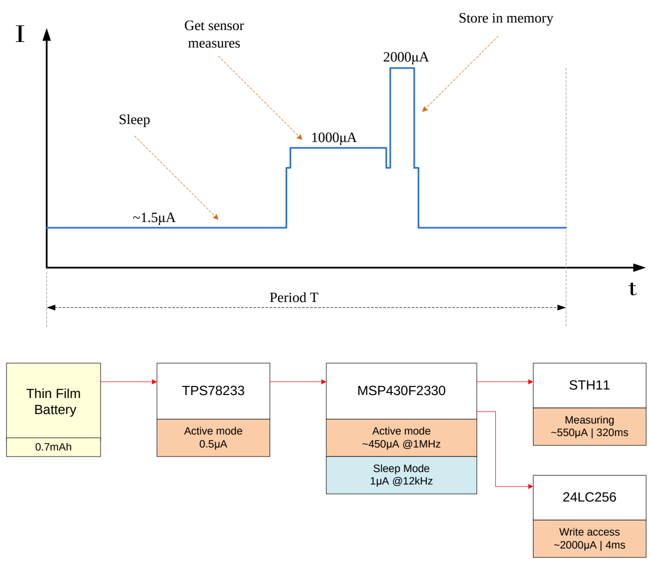

Figure 4 – Current consumption at different transponder operating steps

From Figure 4, the average current/Period (T) can be given by (eq. 1):

$$I_{avg} = \frac{1000uA \bullet 320ms + 2000uA \bullet 4ms + (T - 324ms) \bullet 1.5uA}{T} \quad (1)$$

For a battery with 0.7mAh capacity, the battery lifetime is then given by (eq. 2):

$$W_{time} = \frac{700uA \bullet 3600s}{I_{avg}} \quad (2)$$

Figure 5 presents the battery lifetime for different battery capacities as function of the sampling period. We can see for example, if a measurement period is set to 10mn, a battery with a capacity of 1mAh can been used for about 20 days before starting a new battery charging cycle. A small battery capacity is selected to get a thin form factor for the overall transponder.

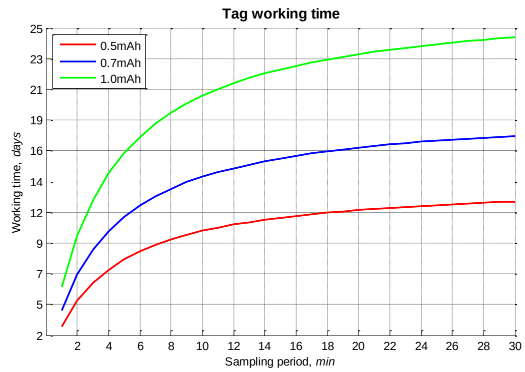

Figure 5 – Battery lifetime as function of the sampling period

IV. ANALOGUE FRONT END (AFE)

To allow free programing RFID transponder, a new RFID Analog Front End (AFE) has been designed and fabricated. Figure 6 is showing the schematic of the AFE.

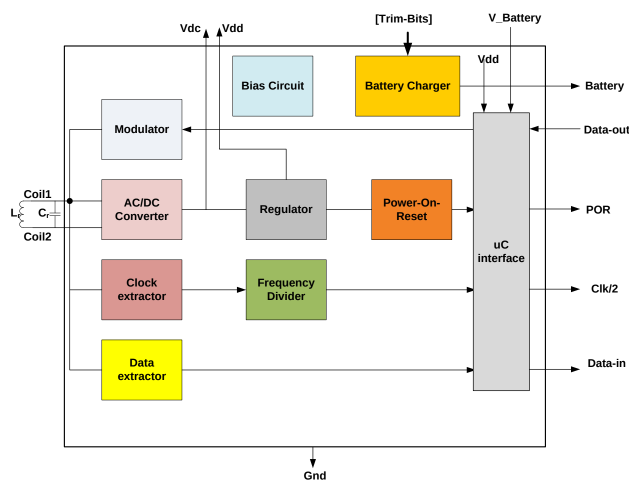

Figure 6 – RFID Analogue Front End Chip (AFE)

The AFE includes the following blocks:

A. *Power Supply*

The on chip power supply is extracted from the exciting field using an AC/DC converter. To avoid over-voltages in high magnetic fields the DC-voltage is clamped. The buffered Supply Voltage passes via a regulator. The output of the regulator is used to power the major part of the analogue front end.

The conventional rectifier is a diode bridge rectifier. The structure of bridge rectifier and its MOS construction are shown in Figure 7.

 ISBN: 978-1-61208-203-5

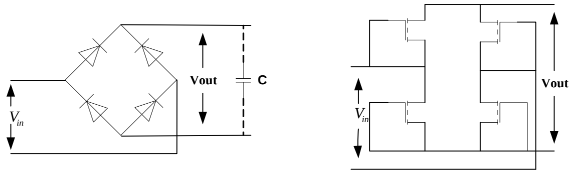

Figure 7 – Diode and MOS bridge rectifier

The diode bridge rectifier output voltage is given by Vout=Vin-2V_{th}.

In the MOS transistors bridge rectifier, the voltage drops are related to the threshold voltage and also the overload voltage, which linearly increases with square root of the current (eq. 3):

$$\Delta V = V_{TH} + \sqrt{\frac{2 \cdot L \cdot I}{C_{ox} \cdot W \cdot \mu}} \qquad (3)$$

To reduce the output voltage drop, the bridge rectifier structure shown in Figure 8 is used. In this structure, the output voltage drop is reduced from two threshold voltages to one threshold voltage.

In Figure 8, NMOS MN1 and MN2 are diode-connected structure, and NMOS MN3 and MN4 are cross-connected structure. L1 and L2 are the input differential signal, when L1 is high, L2 is low, MN1 and MN3 transistors are turn-on, MN2 and MN4 transistors are turn-off and the rectifier has one V_{GS} drop. The opposite operation occurs when L1 is low and L2 is high.

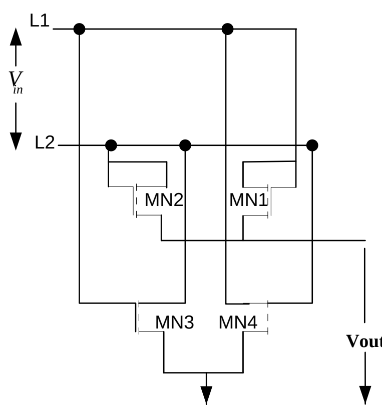

Figure 8 – Cross-connected MOS bridge rectifier

B. *Power On Reset*

The Power-On-Reset (POR) circuit monitors the regulated voltage V_{dd} and generates a global reset-signal putting the chip into an appropriate initial state at power up. It also will guarantee that the chip ceases operating when the supply voltage falls below level necessary for reliable operation. Hysteresis system is provided to avoid improper operation at the limit level

C. *Modulator*

The Modulator will modulate the continuous wave RF signal coming from the reader by changing the Q-factor of the tuned circuit by means of an extra resistive load connected in parallel with the resonance capacitor C_r. These changes in the Q factor induce a corresponding signal in the reader coil.

D. *Clock Extractor*

The clock extractor generates a system clock with the frequency of the RF field. The output signal of this Clock Extractor is passed via a Frequency divider and will then define the on-chip timings.

E. *Data-Extractor*

The data extractor demodulates the incoming signal to generate logic levels and decodes the incoming data.

In the ISO 15693 standard, communication between the reader and the tag takes place using the modulation principle of Amplitude Shift Keying (ASK). Two modulation indexes are used, 10% and 100%. The tag shall decode both. The reader determines which index is used. Data transmission type from tag to reader employs load modulation. When 100% ASK is selected, there is the discontinuousness in the energy of electromagnetism field because of characteristics of modulation type. When 10% ASK is selected, the transmission of energy of electromagnetism field is continuous.

Figure 9 and Figure 10 show the incoming signal and the extracted data in 10% and 100% modulation receptively.

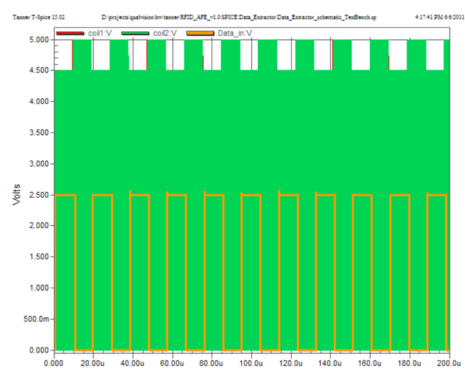

Figure 9 –10% OOK Modulation, Data extraction

Figure 10 –100% OOK Modulation, Data extraction

F. Micro-controller interface

This block allows setting the appropriate voltage levels for the data coming in and out of the AFE.

G. RF Energy harvesting

The important feature of the proposed system is the re-use feature thanks to the battery charger block which will allow re-charging the battery through the RF field.

The battery charger has been designed to allow the charging of a Micro-Energy Cell (MEC®), which is a solid-state, rechargeable thin-film battery. MECs are manufactured by Infinite Power Solutions using wide area thin-film deposition techniques similar to those used to manufacture semiconductors [9]. The MECs enjoy the advantages of rapid recharge and charge acceptance at currents as low as 1uA.

Figure 11shows the block diagram of the battery charger. It consists of a battery current charger and a voltage sensing blocks.

The battery supply (V_{dc}) is obtained by rectifying the power carrier of the wireless link.

The battery current charger consists of reference current and current sources.

The voltage sensing block senses the battery voltage and generates the end-of-charge signal (Charge) so the microcontroller will set the Enable (uc_EN) low to stop the battery charging.

The selection of the current charge level and the battery end-of-charge is done by a trimming method. The trimming circuit was chosen by means of a binary weighted switch network with 11 bits resolution.

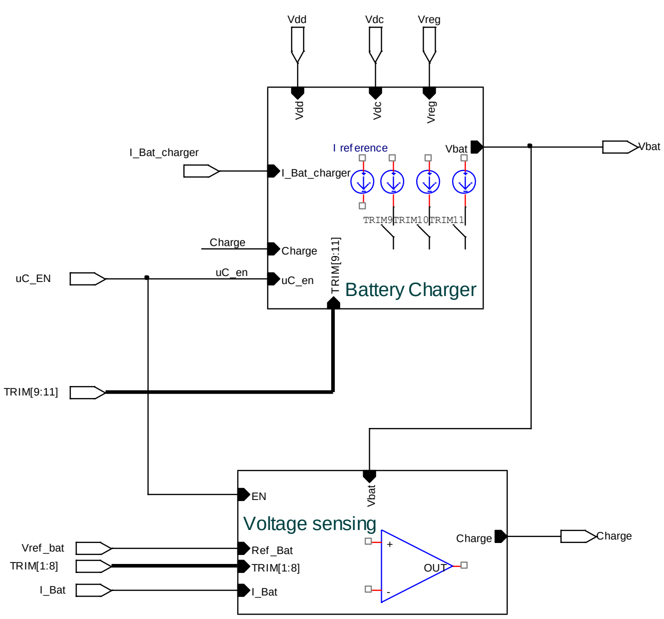

Figure 11 –Block diagram of the battery charger

V. AFE EXPERIMENTAL RESULTS

The proposed AFE has been designed and fabricated successfully using a 0.35um CMOS technology as shown in Figure 12. The overall circuit is 1635um by 1640um.

Before the layout release, every function module of the AFE has been verified by SPICE simulations and by considering the variation of Process, Voltage and Temperature (PVT).

The measured total current consumption of 6uA has been achieved in active mode. The AFE chip operates within a temperature range of -40 to 95°C and a supply range (V_{dc}) of 3-5 V.

A summary of the chip characterization is presented in this section.

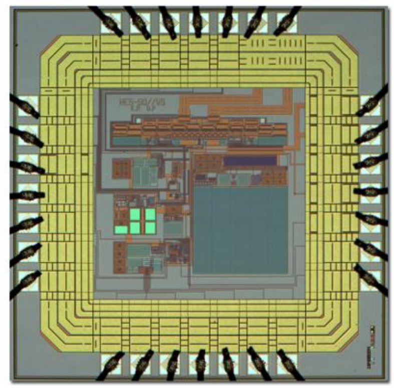

Figure 12 –Die photo of the AFE

A. Reader-Transponder communication

The SMART RFID Sensing Transponder communication platform is fully compliant with the standard protocol ISO15693 [10].

Custom commands for sensing and monitoring have been also developed and implemented.

Figure 13 is showing an example of communication. The reader sends Inventory request Double Sub-carrier, High Data-rate. The data are extracted for the RF field by the AFE (top trace). The transponder responds through the AFE (bottom trace) by sending its UID.

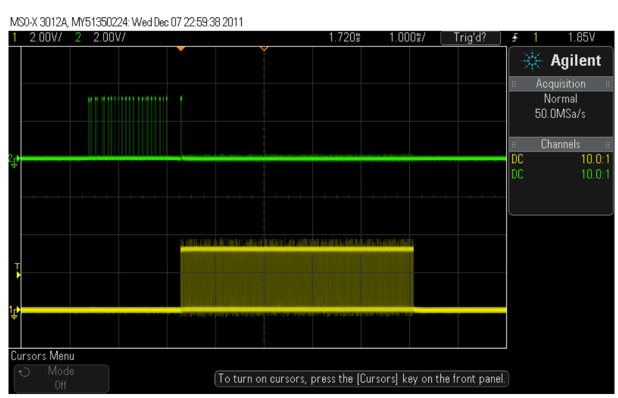

Figure 13 –Reader-Transponder communication: Inventory request

In Figure 14, the reader sends write command (top trace), the transponder responds successfully after 4.5ms (bottom trace).

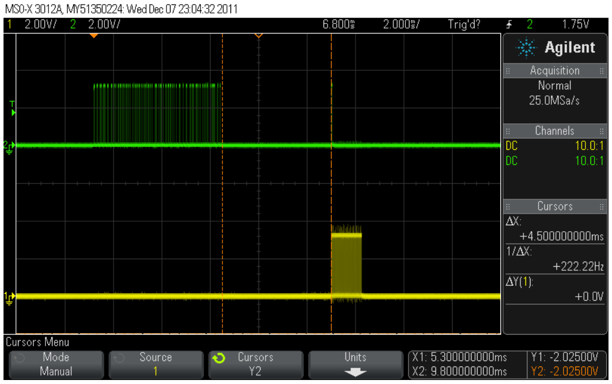

Figure 14 –Reader-Transponder communication: Write command

B. RF enrergy harvesting

To evaluate the battery charger, a capacitor of 100uF was used. The limit test cases are shown below:

a) Case 1

The battery voltage is set to the minimum level of 3.0V with the trimming bits 1 to 8 at low state. The charging current is minimum by setting the trimming bit 9 to 11 to low state (Figure 15).

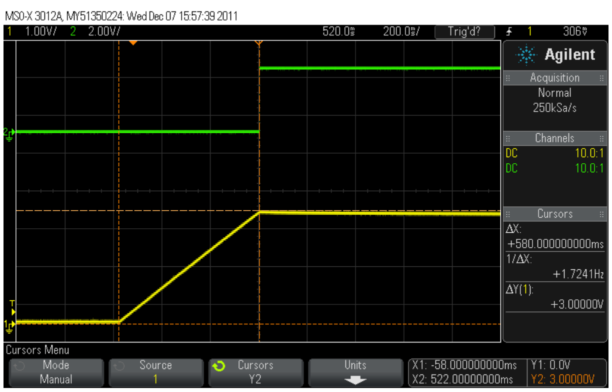

Figure 15: Case 1, All trimming bits are set to low state. TRIM<1:8>= Low, TRIM<9:11>= Low Battery voltage = 3.0V, Charge Time: 580ms

b) Case 2

The battery voltage is set to the maximum level of 4.1V with the trimming bits 1 to 8 at high state. The charging current is increased by setting the trimming bit 9 to 11 to high state (Figure 16).

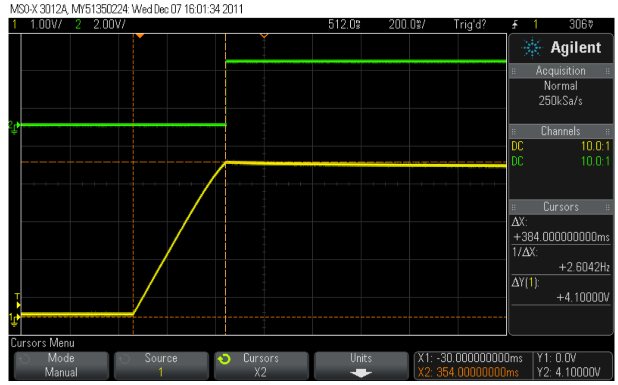

Figure 16: Case 1, All trimming bits are set to high state. TRIM<1:8>= High, TRIM<9:11>= High, Battery voltage = 4.1V, Charge Time: 384ms

VI. CONCLUSION

In this paper, a novel RFID sensing technology that is validated in a Smart, Self-powered, Low-cost and Re-usable transponder system was presented. A batteryless RFID Analogue Front End has been described. The chip was fabricated in a 0.35m CMOS process. The re-use and continuous features are allowed thanks to the designed RF energy harvesting system. In addition, low-power consumption has been achieved by optimizing circuit design and technology.

The power consumption of the used sensors is still high. In future, to further reduce the overall power consumption, low-power temperature and humidity sensors will be designed and integrated within the AFE.

ACKNOWLEDGMENT

This work has been supported by the HES-SO (Project No. 21958). The authors would like to thank the RCSO ISYS scientific committee.

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 ISBN: 978-1-61208-203-5