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RF Powered Gas Wireless Sensor Node for Smart Applications †

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Abstract: Wireless Sensor Network (WSN) paradigm has been applied to a high number of monitoring and control applications. However, the constraint of WSN energy resources imposes restrictions on its truly ubiquitous and long-term deployments. We address the problem of autonomous long-term operation of a gas wireless sensor by employing the far-field RF energy harvesting technology at 900 MHz in the power range from −20 dBm to 10 dBm. The node takes regular CH_4 or *CO* measurements and communicates the data to a wireless network coordinator at 2.4 GHz. Experimental results demonstrate that the optimized energy consumption of WSN, as well as energy harvesting of at least 1 mW (0 dBm) of ambient RF signal, ensure the 'perpetual' operation of WSN.

Keywords: gas sensing; power management; RF harvesting; sensor network

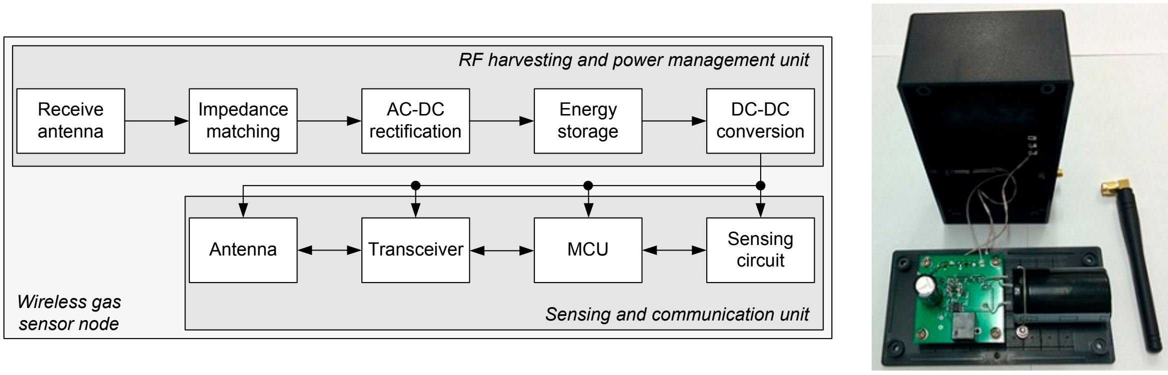
1. Introduction

With the growing interest in the Internet of Things (IoT) where the wireless Sensor Networks (WSN) is one of the enabling technologies, 'Smart-X' applications such as smart city/home/transportation, have tended towards playing a pivotal role in our everyday life [1]. The application of energy harvesting technology to the Wireless Sensor Networks (WSN) turns out to be a popular trend over the last two decades [2] since limited energy resources of WSN restrict their deployment in the applications requiring unattended and long-term operation, e.g., combustible gases detection and air quality control in the cities [3]. The significant progress and adoption of wireless and mobile communications operating at 900/1800/1900 MHz, 2.4 GHz, as well as digital TV, opens up wide vista for far-field RF energy harvesting and its application to powering tiny, autonomous WSN [4].

In this work, we address the problem of autonomous long-term operation of a sensor node by adapting the RF energy harvesting technology for the WSN dealing with the air quality control in the forthcoming era of IoT. Although there has been a tremendous progress in reducing the power consumption of WSN for gas detection and monitoring applications [5,6], the problem of powering the gas wireless sensors using ambient energy has not been investigated properly. We investigate the opportunity of powering the gas sensor node by RF energy at 900 MHz.

2. System Design

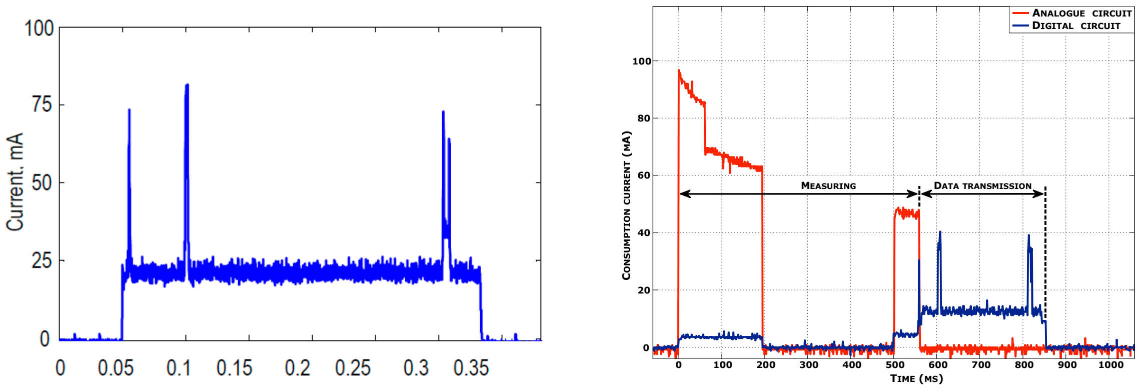
Figure 1 shows the WSN block diagram and associated prototype proposed and designed in this work. It includes two units: (i) processing, sensing and communication, (ii) RF energy harvesting and power management. First, we evaluate the energy budget required to run the first unit which includes microcontroller ATxmega32A4, wireless transceiver ETRX3 2.4 GHz, methane (CH_4) planar catalytic sensor Smartsens and carbon monoxide (CO) electrochemical sensor NAP-505.



(**a**) (**b**)

Figure 1. RF powered sensor node for CO and CH_4 detection: (**a**) block diagram, (**b**) prototype.

Figure 2 shows the current consumption during the CO (a) and CH_4 (b) measurement and wireless data transmission to a wireless network coordinator. For one measurement of CO or CH_4 WSN consumes about 18 mJ or 62 mJ at 2.8 V, respectively. This amount of energy must be accumulated by the second unit for effectuating next measurement and wireless data transmission.



(**a**) (**b**)

Figure 2. Current consumption of WSN during one measurement cycle of: (**a**) CO is 18 mJ, (**b**) CH_4 is 62 mJ.

As an energy storage device, we use a supercapacitor C with operating voltage 5 V. We define its capacitance for recoiling the maximum energy ΔW = 62 mJ to the load as follows:

$$\Delta W = C/2(U^2_{max} - U^2_{min}) \tag{1}$$

where U_{max} and U_{min} are maximum and minimum voltage of supercapacitor.

Voltage U_{min} on the capacitor must not be less than 2.8 V which is determined by the efficiency of the DC-DC converter. According to (1) the capacitance of C should be greater than 7.2 mF. We have chosen supercapacitor with capacity 8 mF. Indeed, the sensor node operated properly in sensing and data transmission modes. However, the network join process is not consistent. Full joining period (initialization + searching + joining) and its success depends on the join duty cycle, ambient conditions and distance between the transceiver and receiver. While experimenting with join process we realized that it may happen that the node joins the network within 5 s and there could be a case when it joins the network after around 40 s of initialization. For avoiding the join process inconsistency we empirically chosen a capacitor of 25 mF which is an excellent trade-off between the reliability of the WSN join process and charging time of the capacitor.

Afterwards we model and design the RF energy harvester operating at 900 MHz and its associated power management circuitry. This unit includes an antenna, LC-resonant circuit performing the impedance matching, AC-DC rectifier and the energy storage. The AC-DC circuit includes the Schottky diodes and the voltage doubling feature. DC-DC TPS61200 performs the stabilization of the output voltage at 2.8 V used to supply the WSN. Supercapacitor (5 V, 25 mF) is chosen based on necessary energy budget for the first unit, power management circuit and optimization requirements [7]. Minimum voltage on the supercapacitor must be 2.8 V. The design goals for the RF energy harvesting unit are associated with achieving highly efficient ambient energy conversion, while the low power consumption is a special focus of the first unit design. All RF-to-DC efficiencies are dependent on input power and decrease with the reduction of input power.

3. Results

Figure 3 shows RF energy harvester output 5 V at input RF power above −2 dBm (0.63 mW).

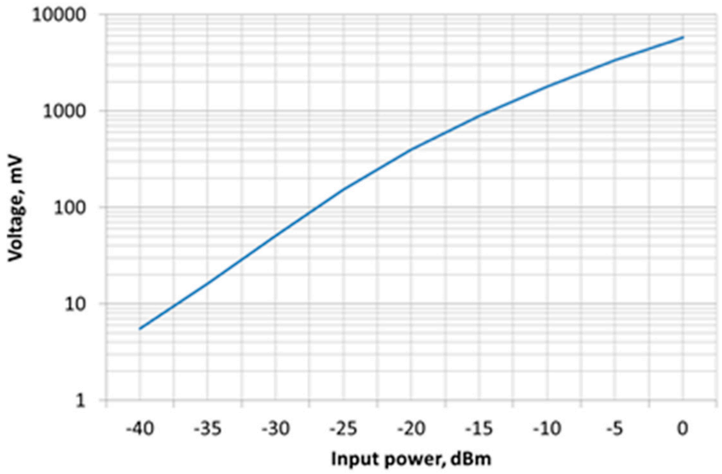


Figure 3. Rectifier output voltage at different input RF power levels.

Figure 4 and Table 1 demonstrate the charging time for 25 mF supercapacitor up to 5 V in different modes and scenarios. These results help modelling the gas measurement procedure. Also, for timing model during the measurement procedure we consider the efficiency of the DC-DC converter at different operating currents and its input voltage levels. Figure 4 shows that charging supercapacitor to 5 V takes 400 s at input RF power 0 dBm. It is the minimum time period between the measurements of CH_4. This time will less for *CO* measurements since just a portion of energy stored in the supercapacitor is consumed.

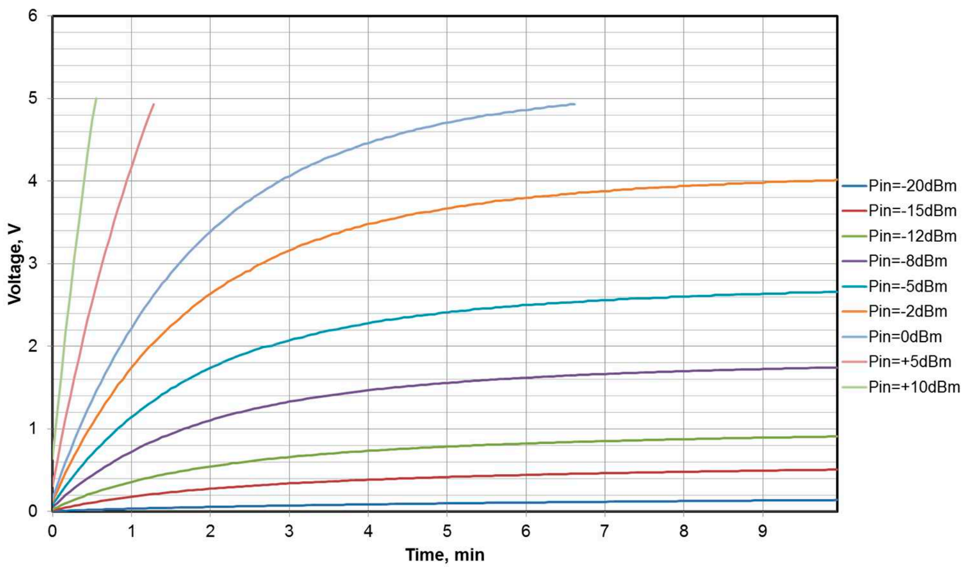


Figure 4. Charging time of 25 mF supercapacitor from the input RF power.

Table 1. Supercapacitor average charging time in different modes using RF harvesting at 0 dBm.

	Measurement and Data Transmission, s	Measurement without Data Transmission, s
Scenario 1: *CO* detection	113	25
Scenario 2: CH_4 detection	400	312

Obviously, the energy consumption during one measurement cycle *without* the data transmission is much less than the same *with* the transmission (see Table 1). In sleep mode the sensor node consumes around 5 μW.

4. Conclusions

We have presented a wireless gas sensor node powered by RF energy at 900 MHz in the power range from −20 dBm to 10 dBm. Experimental results demonstrate that the optimized energy consumption of sensor node, as well as energy harvesting of at least 1 mW (0 dBm) of ambient RF signal, ensure the 'perpetual' operation of the sensor node.

Conflicts of Interest: The authors declare no conflict of interest.

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