RF Powered Gas Wireless Sensor Node for Smart Applications

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Introduction

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 -20dBm to 10dBm. The node takes regular CH4 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.

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 (CH4) planar catalytic sensor Smartsens and carbon monoxide (CO) electrochemical sensor NAP-505.

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 CH4 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.
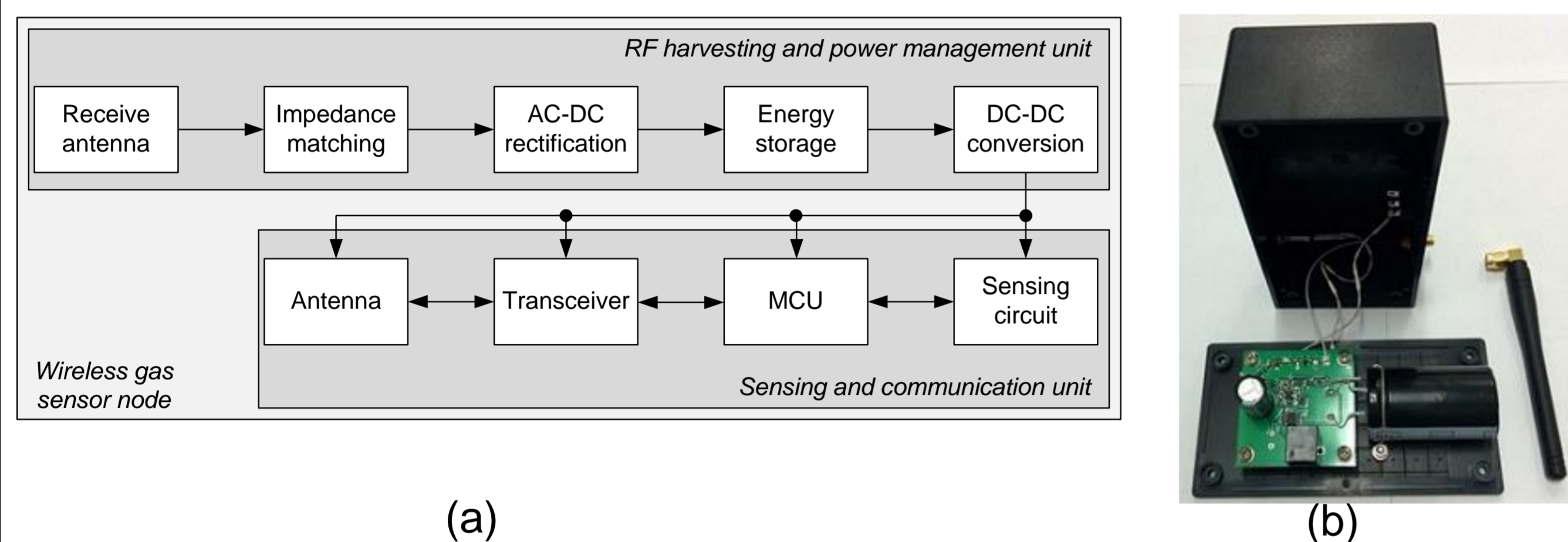

(a)   (b)

Figure 1. RF powered sensor node for CO and CH4 detection: (a) block diagram, (b) prototype

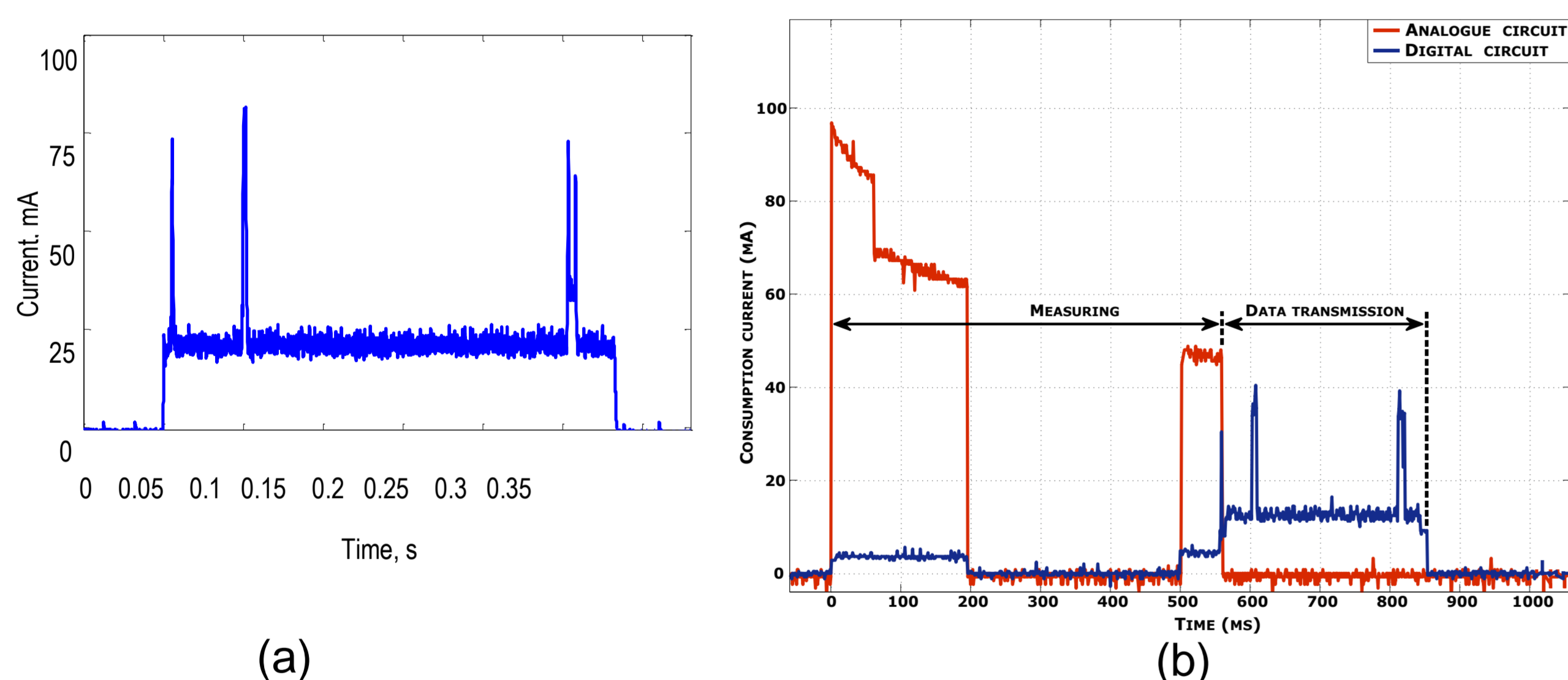

(a)   (b)

Figure 2. Current consumption of WSN during one measurement cycle of: (a) CO is 18 mJ, (b) CH4 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 W=62 mJ to the load as follows:

$$W= C/2 \ (U^2max-U^2min) \qquad (1)$$

where Umax and Umin are maximum and minimum voltage of supercapacitor.

Voltage Umin 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 (5V, 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 2.8V. 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.

Experimental results

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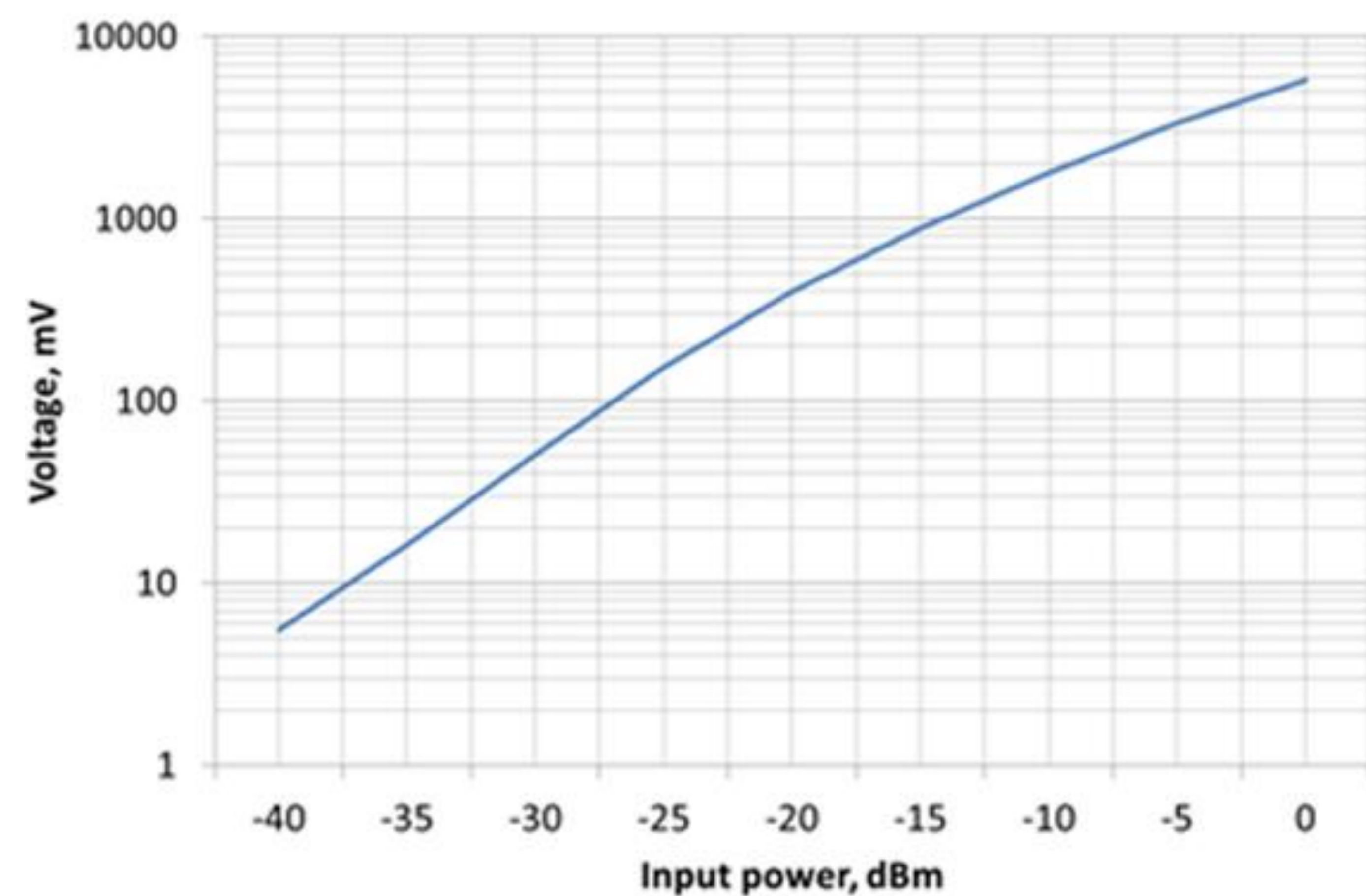

Figure 3. Rectifier output voltage at different input RF power levels.
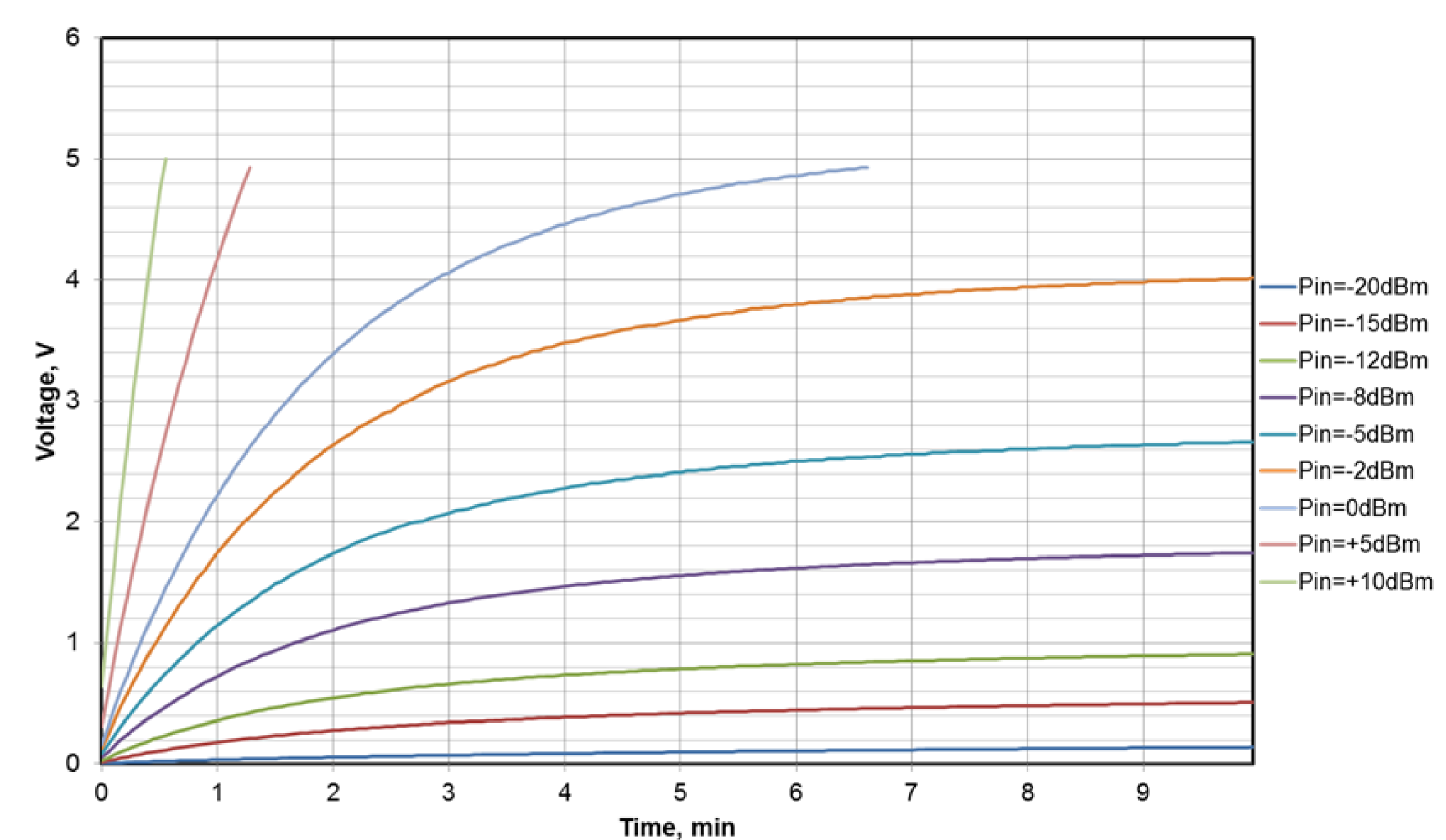

Figure 4. Charging time of 25 mF supercapacitor from the input RF power.

Figure 4 and Table 1 demonstrate the charging time for 25 mF supercapacitor up to 5V 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 CH4. This time will less for CO measurements since just a portion of energy stored in the supercapacitor is consumed.

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: *CH4* 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.

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.

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