Study of the communication distance of a MEMS Pressure Sensor Integrated in a RFID Passive Tag

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***Abstract*—The performance of a MEMS (Micro Electro-Mechanical Systems) Sensor in a RFID system has been calculated, simulated and analyzed. It documents the viability – from the power consumption point of view- of integrating a MEMS sensor in a passive tag maintaining its long range. The wide variety of sensors let us specify as many applications as the imagination is able to create. The sensor tag works without battery, and it is remotely powered through a commercial reader accomplishing the EPC standard Class 1 Gen 2. The key point is the integration in the tag of a very low power consumption pressure MEMS sensor. The power consumption of the sensor is 12.5µW. The specifically developed RFID CMOS passive module, with an integrated temperature sensor, is able to communicate up to 2.4 meters. Adding the pressure MEMS sensor - an input capacity, a maximum range of 2 meters can be achieved between the RFID sensor tag and a commercial reader (typical reported range for passive pressure sensors are in the range of a few centimeters). The RFID module has been fabricated with a CMOS process compatible with a bulk micromachining MEMS process. So, the feasibility of a single chip is presented.**

***Index Terms*—radiofrequency identification, sensor systems, low power electronics, wireless sensor networks.**

I. INTRODUCTION

RFID systems could have many applications. Recently, RFID is being used in new ones, such as sensoring [1-2]. For instance, RFID could be useful for patient, medicaments, and blood bags identification and monitoring [3]. However, few MEMS sensors are connected to a RFID passive tag due to the high power consumption of these sensors. This work searches the theoretical validation of this idea for some applications. Moreover, the objective is to establish the challenges and limitations of the RFID passive solutions in order to power MEMS sensors. The power available to drive the RFID tag is extremely low. The typical sensor consumptions are an order of magnitude over the total power available at the tag. Thus, the difficulty to drive the tag and a sensor is even greater. Nevertheless, passive tags are more interesting as they are cheaper than semi-active or active tags -obvious since they do not need battery nor packaging-. Moreover, they have a longer life-time and smaller dimensions. Therefore, it is clear that any device that would be able to measure a magnitude with passive long range RFID tags may become an advance of the technology state of the art and multiplies the applications in commercial products due to its reduced price.

Temperature, magnetic field or light sensors may be fabricated using CMOS technologies for determined ranges. However, there are other magnitudes impossible to measure with CMOS technologies, such us displacement, velocity, acceleration or pressure. MEMS technology must be used for the fabrication of these kinds of sensors. Some typical applications are: enhancement of GPS navigation; in and out-door navigation; leisure and sports; weather forecast and vertical velocity indication; perhaps the last one is the most interesting for our purpose (wireless passive sensing).

The present work has been developed in the UHF band (860-960MHz). The maximum radiated power for this frequency range -regulated by a European Law [4]- is 2W ERP. This brief is organized as follows: the System Architecture is reported in Section II. Section III describes the performance simulation of the integrated MEMS in the RFID passive tag. Section IV presents the measurement setup and the results. Finally, Section V discusses the achieved communication distances and new possible applications.

II. SYSTEM ARCHITECTURE

A RFID system is composed by two main blocks: a reader and a tag [Fig. 1]. The reader transmits the information through Radio-Frequency waves. The tag captures this information and, if requested, sends its identification and some extra information back to the reader. RFID offers instantaneous information about the tagged item. It does not need contact or even line of sight and it is able to identify individual units massively just with a single reader.

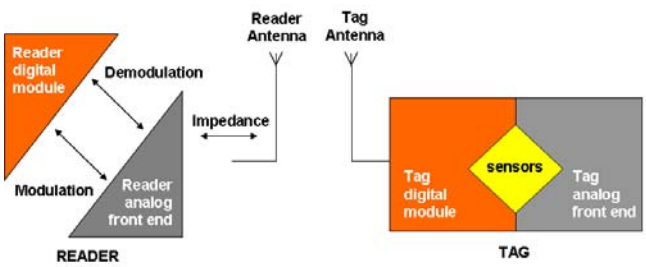

Figure 1. Full RFID System.

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A high level explanation of how the system works is presented:

1. The reader sends power and communication via Radio Frequency.
2. The tag's antenna captures the energy that starts the operation of the front end.
3. The front end demodulates the communication signal and provides a frame of bits to the Digital Core for processing.
4. The digital core requests the temperature sensor and the MEMS pressure sensor for calibration and information.
5. The sensors perform the necessary measurements and send the required information to the Digital Core.
6. The Digital Core processes all the data and sends it back to the front end.
7. The front end modulates the information and transmits it back to the reader via backscattering.
8. The reader receives the information and shows it in a configurable display.

The reader employed for the communication is the MC9090-G Handheld RFID Mobile Computer of Motorola [5], which has a data rate of 100 kbps and allows an Output Power of 2W. This data rate is enough for our application. The maximum frequency of data acquisition will be determined by the standard EPC Class 1 Gen2, which specifies the time duration of each command [6].

A RFID tag prototype –which incorporates a temperature sensor-, has been designed to allow the connection and power supply of a MEMS sensor [Fig. 2]. Each part of the sensor tag is described in the following lines.

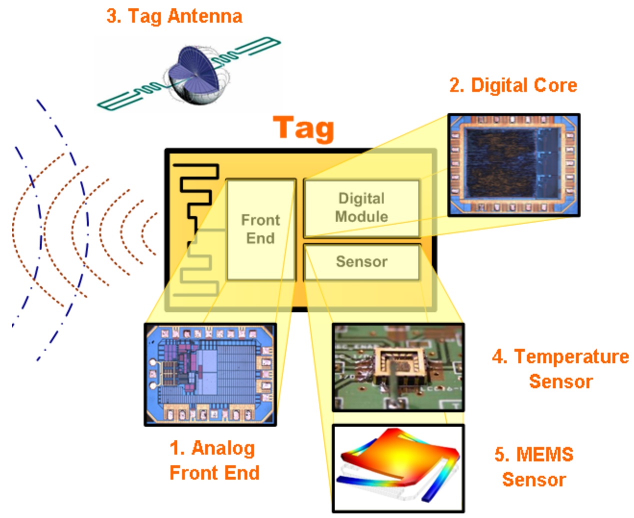

Figure 2. RFID Tag.

A. *Analog Front End*

A long range, low power analog front end suitable for battery less wireless sensors has been designed using a low cost 0.35-μm CMOS standard process [7]. The front-end architecture allows the implementation of power management techniques to provide a long reading range. The implemented voltage multiplier uses Schottky diodes to make available efficiencies higher than 35%.

B. *Digital Core*

The digital core complies with the EPC Class 1 Gen 2 communication standard, and uses an owner protocol to communicate with the temperature sensor. The communication with the MEMS sensor should be with an I2C or SPI interface.

Although our aim is to combine the digital core with the analog front end in an Integrated Circuit (IC), for our studies we have used a Field Programmable Gate Array (FPGA) where this code can be easily synthesized. It contains programmable logic components and a hierarchy of reconfigurable interconnects between them. Those logic blocks can perform complex combinational functions or functions of simple logic gates (such as AND or XOR). The main advantage of working with the FPGA is that it let us modify the digital core effortlessly to check the communication with different MEMS sensors.

Though the FPGA is supplied externally, the power consumption of the digital core can be emulated by means of a load. This is required if we want to verify the maximum communication distance; as the front end has to supply the energy to the digital core. The value of this resistor has been calculated considering the power consumption of the post-layout simulations of the digital core: 20 μW. The load is connected to the 1.2V regulator, so it must comply:

$$P = I \cdot V = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{P} = \frac{1.2^2}{20\mu} = 72k\Omega \qquad (1)$$

The architecture of the digital core used for this work is presented in [8].

C. *Antenna*

It is responsible for converting the electromagnetic wave into a voltage source. A good matching between antenna and chip is required for maximizing the input power and, as a consequence, the reading range. This objective has been attained designing a dipole antenna to be tuned in the 865MHz-868MHz UHF RFID European Band. The use of a dipole antenna presents a loss of 3dB, due to the fact that it has linear polarization, whereas the reader uses circular. The maximum theoretical gain is 1.64 (2.15dB), whereas the minimum is 0 in the X axis.

D. *Temperature Sensor*

The temperature sensor is based on a ring oscillator, where the temperature dependence of the oscillation frequency is used for thermal sensing. The temperature sensor exhibits a resolution of 0.035ºC and an inaccuracy value lower than 0.1ºC in the range from 35ºC to 45ºC after two-point calibration. The average power consumption of the temperature sensor is only 110nW at ten conversions per second while keeping a high resolution and accuracy [9]. As the power consumption is very low it is attractive to incorporate this sensor in the tag, although it could not be required for some specific applications.

E. *MEMS*

Even though the sensors consume very low power, they have a initial power consumption that requires an external capacity to prevent the discharge at the startup of the sensor, which represents a current consumption peak. The capacitor charges itself when it receives power from the reader. A detailed analysis of the value of the capacitance can be found at [10]. The commercial sensor that has the lowest power consumption and is useful for our applications is the one of Bosch Sensortec [Table I].

TABLE I. CHARACTERISTICS OF THE SELECTED MEMS SENSOR

BMP085 Sensor	Characteristics
Manufacturer	Bosch Sensortec
Sensor type	Barometric Pressure
Pressure range	30-110kPa
Accuracy	0.15kPa
Resolution	0.001kPa
Supply voltage	1.8-3.6V
Current consumption	3-5-12μA
Standby consumption	0.1μA
Interface	I²C

Fig. 3 shows the prototype that has been designed and fabricated. The low power consumption of each module is crucial because all the sensor tag has to be powered by the RF signal. As it has been mentioned before, the power consumption of the digital core has been emulated by means of a resistance that represents the consumption of the digital core that could be fabricated in the 0.35-μm CMOS technology. There are some pines of the FPGA prepared to connect a MEMS sensor at 2.5V.

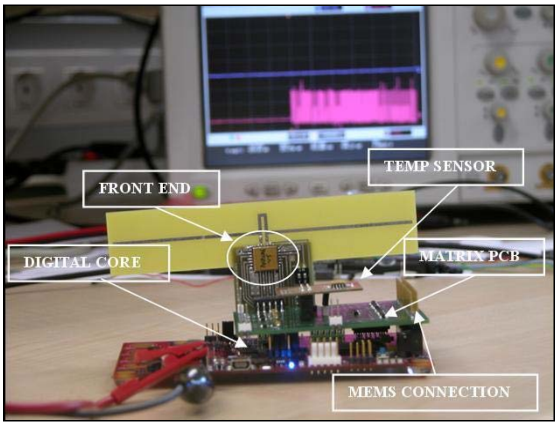

Figure 3. Prototype of the sensor tag where the MEMS can be connected.

The power consumption is very useful to predict the simulation study of the communication distance that will reach the sensor tag. It is presented in the Table II.

TABLE II. MEASURED POWER CONSUMPTION OF EACH MODULE OF THE PROTOTYPE.

Module	Power Consumption
P_{ANALOG}	20μW
$P_{DIGITAL}$	20μW
$P_{TEMP\ SENSOR}$	<1μw

III. PERFORMANCE SIMULATION

The Friis transmission equation for Free Space defines the achievable distance between reader and tag as a function of the tag consumption (PAV). The PEIRP is fixed at the maximum defined by European laws in order to reach the maximum communication distance.

$$dis = \sqrt{\frac{P_{EIRP}\lambda^2}{16\pi^2 P_{AV}}} \qquad (2)$$

The power required at the antenna is calculated considering the tag power consumption and the transmission losses. The consumption of the analog and digital parts has been previously measured, as well as the voltage multiplier efficiency and the antenna gain.

The total power required at the tag input may be expressed as follows:

$$P_{AV} = \frac{(Pdig + Pan + Psens)}{\eta * G} * Z_{mismatch} * Pol_{mismatch} \qquad (3)$$

Where,

Pdig is the digital block power consumption.

Pan is the analog block power consumption.

Psens is the sensors power consumptions, MEMS and Temperature.

Zmismatch = 1-|reflCoeff|², is the ratio of the power available after impedance mismatch.

Polmismatch is the ratio of the power available due to polarization mismatch. As the Reader polarization is circular and the tag polarization is linear, this ratio will be 50% (-3dB).

η is the efficiency of the voltage multiplier.

G is the gain of the tag antenna.

The sensor current consumption has been assumed in order to estimate the maximum communication distance between the reader and the tag. The voltage supply has been fixed at 2.5V, the required voltage for the MEMS sensor.

Not only a minimum input power is necessary at the tag antenna, but it is also required a minimum voltage swing at the input of the voltage multiplier. This will allow a proper performance, with good efficiency and the achievement of the required supply voltage for both analog and digital circuits at its outputs. Equation 5 provides the relation between the necessary voltage at the output of the voltage multiplier and the distance between tag and reader [3]. An increment of Vmin implies a reduction of the range. So a minimum Vmin is desired. But this parameter depends on the technology employed.

This constraint is not usually included in the system analysis of the RFID bibliography, although it could be the limitation of the maximum achievable communication distance. In our system, the Equation 4 constraint is more significant than the limitation of Equation 5.

$$dis = \sqrt{\frac{P_{EIRP}\lambda^2 G\eta}{16\pi^2 \left(Z_{mismatch} * Pol_{mismtach}\right)\left(P_{ANA} + P_{DIG} + P_{SENS}\right)}} \qquad (4)$$

$$dis = \frac{0.7 Q_{mn}\lambda\sqrt{P_{EIRP} G R_A}}{4\pi V_{min}} \qquad (5)$$

Where, Qmn is the quality factor of the matching network, RA the antenna impedance and λ the wavelength.

Besides, a more restrictive worst case estimation has been done using several security factors that increase consumptions and losses.

TABLE III. CONSUMPTION OF THE RFID TAG MODULES AND THEORETICAL MAXIMUM COMMUNICATION DISTANCE

Item	Typical Case		Factor	Worst Case	
P_{ANALOG}	20	μW	3	60	μW
$P_{DIGITAL}$	20	μW	3	60	μW
P_{SENSOR}	2.5	V	1	2.5	V
	5	μA	1	5	μA
	12.5	μW		12.5	μW
P_{CORE}	52.5	μW		132.5	μW
VM eff	40.00%	-	4	10.00%	-
P_{IC}	131.25	μW		1325	μW
$Z_{MISMATCH}$	20.00%	-		50.00%	-
Polariz. looses	50.00%	-		50.00%	-
Antenna G_{MIN}	0.88	-	1	0.88	-
P_{AV}	373	μW	16	6022.73	μW
Distance	2.01	m		0.50	m

The distance (2.01 meters) has been calculated with the typical case values using the previous equations. Although the typical current consumption value of the MEMS sensor is 5μA other values are simulated and plotted in the Fig 4.

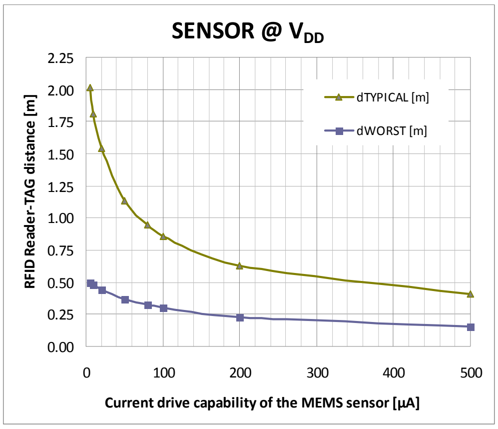

Figure 4. Simulated communication distances.

IV. Measurement Setup and Results

The measurement environment consists of two main parts. The first one is the reader side, which has an antenna, a receiver and a transmitter. It has been programmed to allow the correct interpretations of the magnitudes measured by the sensors. The second one represents the prototype as a RFID sensor-tag environment, where additional measurement devices are connected for observing purposes. For visualization of the raw communication an oscilloscope and a spectrum analyzer were used.

The measures are made in an anechoic chamber without the MEMS sensor, so taking into account only the consumption of the tag. It has been calculated the power needed by the tag to operate at different frequencies and the distance at which the sensor has a proper performance [Fig. 5 and Fig. 6].

The communication distance higher than 2 meters matches the simulations and verifies the mathematical estimations. The measured distance has been 2.40 meters so it is coherent with the theoretical approach.

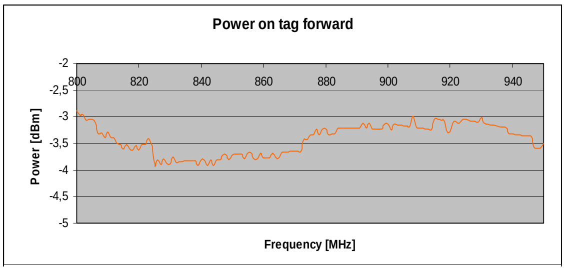

Figure 5. Frequency Sweep of the Power needed at the tag.

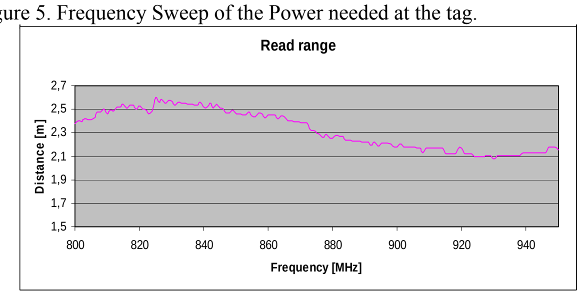

Figure 6. Frequency Sweep of the Read Range of the tag.

In order to attain the maximum communication distance with the MEMS integrated, the sensor consume (typical 12.5µW) should be added. As shown in the simulations -by applying the Friis formula- the achieved range would be around 2.01 meters. Analyzing other low power consumption MEMS pressure sensors such as [11], [12] and acceleration sensors [13] we can predict communication distance above 1 meter with many other applications.

V. Conclusions

The results show a great improvement in the communication range regarding the state of the art [14]. This is a milestone for the MEMS sensors, allowing their integration in long range passive RFID systems.

As new sensors appear in the market –new range pressure sensors or other magnitudes sensors- the number of potential applications grows significantly. Additionally, more than one MEMS sensor could be powered by the same passive tag. Besides, the designed RFID tag has been prototyped in 0,35-µm process and some foundries are working on integrating MEMS technologies with CMOS 0,35-µm [15]. So, the feasibility of a single chip solution has been verified.

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References

[1] K. Opasjumruskit, "Self-Powered Wireless Temperature Sensors Exploit RFID Technology," IEEE Pervasive Computing 5(1), 2006. pp. 54-61. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1593572

[2] N. Cho, "A 5.1-mW UHF RFID Tag Chip integrated with Sensors for Wireless Environmental Monitoring," European Solid-State Circuits Conference (ESSCIRC). 2005. Grenoble: IEEE, pp. 279-282.

[3] Pardo, D. "Design criteria for full passive long range UHF RFID sensor for human body temperature monitoring," Proceedings of IEEE RFID Conf., Mar. 2007, pp. 141–148. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4143523

[4] ETSI EN 302 208-1 V1.1.2 Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio Frequency Identification Equipment operating in the band 865 MHz to 868 MHz with power levels up to 2 W. 2006.

[5] Motorola, MC9090-G RFID, http://www.motorola.com/

[6] EPC-C1G2, Specification for RFID Air Interface. EPC Global Class 1 Gen 2 UHF RFID Version 1.2.0. EPC GlobalTM, 2008.

[7] A. Vaz, "Long range, low power UHF RFID analog front end suitable for battery less wireless sensors," IEEE IMS, 2010. p. 836–839. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=05518072

[8] I. Zalbide, J. Vicario, I. Velez, "Power and energy optimization of the digital core of a Gen 2 long range full passive RFID sensor tag," Proceedings IEEE RFID Conf., 2008, pp. 125–133. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4519354

[9] A. Vaz, A. Ubarretxena, I. Zalbide, D. Pardo, H. Solar, "Full Passive UHF Tag With a Temperature Sensor Suitable for Human Body Temperature Monitoring," IEEE Transactions on Circuits and Systems II Express Briefs (2010). Volume: 57, Issue: 2, Pages: 95-99. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=05411829

[10] I. Zalbide, J. F. Sevillano, I. Vélez, "Design considerations for the digital core of a C1G2 RFID Tag," Chapter in the handbook: Radio Frequency Identification Fundamentals and Applications Design Methods and Solutions, Editor: Cristina Turcu (Ed.), ISBN: 978-953-7619-72-5 (2010).

[11] VTI Technologies, Datasheet from VTI (SCP1000). [Online]. Available: www.vti.fi/en/news-events/enews/012006/scp1000/

[12] Freescale, Datasheet from Freescale (MPL115A). [Online]. Available: www.freescale.com/files/sensors/doc/fact_sheet/MPL115AFS.pdf

[13] Bosch Sensortec, Datasheet from Bosch (BMA222). [Online]. Available: http://www.bosch-sensortec.com/content/language1/downloads/BST-BMA222-DS002-02.pdf

[14] Jingtian, Xi. Low-cost low-power UHF RFID tag with on-chip antenna. Journal Semiconductors, 2009. v. 30 075012.

[15] XFAB, Semiconductor Foundries, [Online]. Available: http://www.xfab.com/