RFID based solution for the sensing of home electrical devices activity

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***Abstract* - A disruptive solution for sensing the activity of electrical devices connected to the home power line, based on the use of a long range UHF RFID system, is proposed. The solution uses a flexible RFID tag sensor wrapped around the power cord of the electrical device to be sensed. In addition to the identification of the device, the RFID tag has the unique property of detecting the status change, that is, the ON/OFF state of the device. A preliminary prototype using an external sensing acquisition block realized on a PCB connected to a flexible substrate holding the RFID antenna, have been realized and successfully tested. A sensing range of approximately 5-6 m using a regular RF reader operating in the UHF band, have been obtained, despite the close proximity of the power cord.**

***Index Terms* — RFID, UHF antenna, RFID sensor, Current impulse, Magnetic coupling.**

1. Introduction

The knowledge of the status (ON or OFF) of home electrical devices connected to the home powerline, with fine granularity (i.e. device granularity), provides good insights on what is going in the household and opens the door to many innovative applications and services in different areas which go beyond the energy monitoring application, such as elderly care or recommendation systems. Existing solutions use a so called smart plug to be plugged into the power outlet of the device to be sensed [1]. Such solutions require to buy a monitoring smart plug which costs around $50 for each device in the home. Additionally, they are ill-suited for devices which are not necessarily powered from an outlet (e.g. lighting) or for portable devices that move from one outlet to another.

In this paper, a novel cost-effective for wireless sensing of the electrical devices, easy to deploy, is presented. This solution is based on the use of a long range RFID system operating in the UHF band.

2. Overview of the proposed solution

Fig. 1 presents an example of switch ON/OFF impulse responses, measured on a lamp desk, using a small wire loop coupled to the power cord. These typical responses, including the noticed different switch ON and switch OFF behaviors, have been found in extensive measurements made on various home electrical devices/appliances. The fundamental mechanism of the current impulse, also called transient electrical noise, is well known and gives rise to damped oscillatory current/voltage with amplitude and frequency depending on the distributed and lumped loads connected to the power network [2].

The idea is to wrap, around the power cord of the electrical device to be sensed, a flexible RFID tag which has the unique property of detecting the current impulse appearing along the power cord at each switch ON/OFF of the device and storing this information in the memory of the RFID chip. Therefore, the status information could be transmitted with the ID of the tagged device when placed in the range of a standard RFID reader operating in the UHF band. The energy of the current impulse, coupled through an optimized antenna design, is found sufficient to activate the RFID chip and to write the information of the status change in the chip memory, for example by modifying one bit value in the memory.

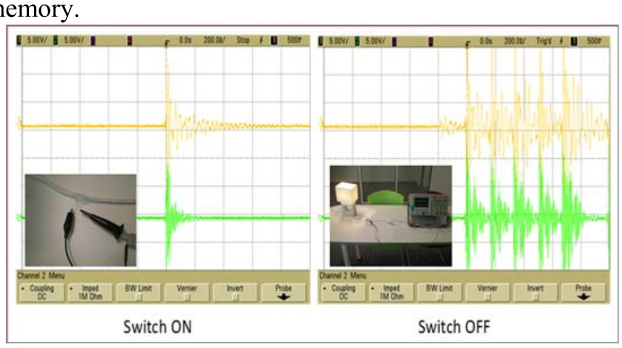

Fig. 1. Switch ON/OFF impulse responses measured at 2 different points of a desk lamp power cord

The key component of the proposed solution is the RFID impulse sensing tag. It requires for the long term the design of a dedicated RFID chip which integrates a current impulse detection block realized using a simple state machine architecture typical of RFID passive tags.

However, for the proof of concept, a preliminary prototype, was realized using an external impulse acquisition block made on a separated Printed Circuit Board (PCB) using discrete components associated to a new generation of RFID chip [3]. The latter offers, in addition of the antenna interface a second wired I^2C interface which is used for updating the “status bit” in the chip memory at each impulse detection. The functional architecture of the realized prototype with physical partitioning between the flexible substrate and the PCB are shown in Fig. 2. The PCB also includes an ultra-low power microcontroller and a small battery required for powering the impulse detector block, the microcontroller and the I^2C functionality of the new generation of RFID chip.

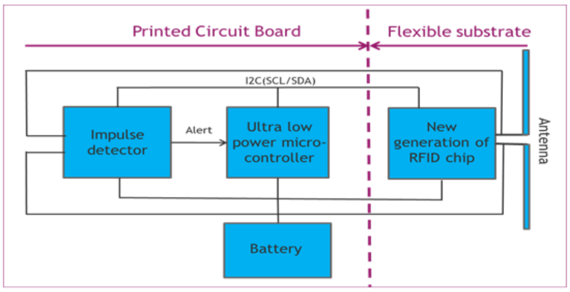

Fig. 2. Functional architecture and physical partitioning of the realized impulse sensing RFID tag prototype

3. Design of the key components of the preliminary prototype

(1) Impulse coupling RFID antenna

The design objective of the impulse coupling RFID antenna is two-fold: the antenna should insures the best possible coupling to the impulse and at the same time it should works as an efficient antenna in the UHF RFID band (typically 860-960 MHz), despite its close proximity to the power cord around which will be wrapped. The topology of the optimized solution, designed on a thin Polystyrene substrate with adhesive in the back side is presented in Fig. 3. It is composed by a double square loop magnetically coupled to a half-wave dipole and connected to the RF input of the RFID chip of new generation. While the straight dipole fits well to the power cord shape factor, the choice of the double-rectangular loop allows an optimal coupling to the impulse when the antenna is wrapped around the power cord. The loop should also be connected to the external impulse acquisition block through 2 decoupling inductances. The interconnection strip includes connections for I^2C bus, impulse signal, power supply and ground.

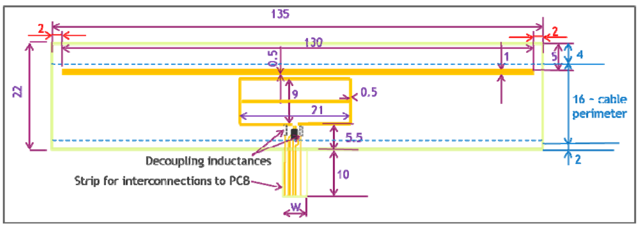

Fig. 3. Optimized design of the impulse coupling RFID antenna

A new generation RFID chip from NXP (Ref. [3]) was used and design rules, aiming to equal the real and imaginary parts of the antenna input impedance to the conjugate of the RFID chip input impedance in the UHF band, are given in Ref. [4]. The design was optimized using HFSS while taking into account the power cord.

(2) PCB design including the impulse acquisition block

The PCB hosts the external impulse acquisition circuit (IAC), the ultra-low power microcontroller (UMC) from Microchip (Ref. PIC16LF1823), a small battery and various connectors for tests and UMC programming. The IAC, presented in Fig. 4, is based on a very low-power ADC from Texas Instruments (Ref. ADC081C021). It includes an Alert function which provides an interrupt that is activated when the analog input impulse signal exceeds a programmable threshold level. Due to the very short time duration of the impulse and the relatively limited speed of the ADC, a “preconditioning” circuit aiming mainly to expand the time duration of the impulse is placed between the impulse input at the strip level and the ADC. The “preconditioning” circuit uses surface mount Schottky diodes from Agilent (HSMS 2811) and C1 and C2 values are optimized so that the ON and OFF states could be discriminated.

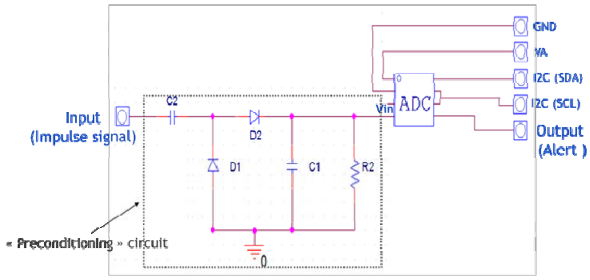

Fig. 4. Impulse acquisition circuit

4. Realized prototype

Fig. 5 shows the realized prototype. The flexible part is wrapped around the power cord and connected to the designed PCB using a standard connector. Performed extensive tests on various home electrical devices showed a read range of approximately 5-6 m with a standard RFID reader operating in the US 915 MHz RFID band.

Fig. 5. Photograph of the realized power cord impulse sensing RFID tag

5. Conclusion

A cost effective solution for wireless sensing of home electrical devices have been designed realized and successfully tested. The solution uses commercial off-the-shelf components and costs approximately $4 or $5 which is almost 10 time less than the commercially available solutions for monitoring electrical devices.

Acknowledgment

We are grateful to the French National Research Agency (ANR) for their support of this work within SENSAS project

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