Development of Wireless Passive Sensing Platform – Communication Issues

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Abstract. This paper presents a concept and investigations on wireless sensing platform utilizing Radio Frequency Identification (RFID) technology. The platform should serve as a completely passive wireless communication interface between any connected sensor (strain gauge, accelerometer, pressure sensor) and standard RFID reader. Entire energy needed for powering is delivered via magnetic coupling between the reader and a planar coil antenna, which is one of the platform parts. The same electromagnetic signal serves for communication and data acquisition based on backscattering technique. Designed platform could be used in many applications, especially in structural health monitoring (SHM) and for advanced diagnostic purposes. Scope of the parts of investigations presented in this work was acceleration of data rate between the platform and the reader. Efficient data transfer is the primary problem in many potential applications. By improvement of communication and data storage algorithms, as well as testing of different types of RFID readers, we achieve effective data rate on the level of 18 Kbit/s. By meaning of the effective data rate, it is defined data stored from sensor on EEPROM memory, not only UID, that is transferred in typical RFID systems.

Keywords: wireless sensing platform, passive RFID, data rate.

1 Introduction

Development of sensors based on RFID technology is an easily noticeable trend in recent years. Using of specific properties related to wireless, passive communication technology allows to design sensor systems powered wirelessly without any battery. Generally there are two approaches to development of such sensor system. The first one could use transponder and its physical properties as a sensing element, the second method assumes the use of RFID transponder as a type of platform, to which one could connect a specified, low-energy sensor. Both approaches with given examples are well described in [1]. From the point of view of this paper, the most interesting reports are related to the investigation on different sensing platforms based on RFID technology with especially scope on the problem of wireless data transfer between the platform and the reader. The most advanced sensing platform is called WISP. It is widely described in many papers. One of the most accurate, related to design and performance is [2]. Any research institute could contribute to the development and

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thanks to this open form of the project, many papers reporting this specific application were released. One of the most interesting, related to using of WISP for the state monitoring of carbon fiber composites structure, was reported in [3]. Another sensing platform, called wireless sensor interface, in the form of specifically developed integral circuit was presented in [4]. Solution similar to that presented in this paper was reported in [5], however despite of using the same frequency band, which is the high frequency HF with the range of 13.56 MHz, reported read range is much smaller than in our solution. Other papers describing problem of data transfer are presented below. Summarizing, there are different reports concerning development of passive sensing platforms, but some of their properties cause that there is still need to search for solution better matched to defined requirements. In the case of the first platform, the problem is related to a complicated way of data transfer within ID number of the tag. In the case of the second one, the platform has not been implemented in wider application and is not available for testing. In the third one, the problem lies in a small read range.

The most important problem, from the point of view of this paper is the issue of data rate between sensing platform and typical RFID reader. Data rate in RFID systems is the complex problem concerning the versatility of RFID standard. The main reason are anti-collision algorithms which are used by any standard reader and give possibility to read as many RFID tags as it is possible in the shortest moment of time. Basic norms related only to HF and UHF range, which is in our concern, are ISO15693 and ISO18000-3 for HF and ISO18000-6 for UHF systems. Values of data rate given in norms are in the range from 6.62 Kbit/s [6] to 105.9375 Kbit/s [7] for HF systems and 40 Kbit/s for UHF [8]. The important thing is that the data rate is on sufficient level for typical RFID application, which is identification of many transponders with short UID, which states no load for communication algorithms. The problem starts, when one wants to use the RFID system for the purpose of large data transfers, for instance from the connected sensor. In this case, provided values of data rate do not correspond with reality. Unfortunately referenced papers give no straight information related to data rate of described systems and these information could be only deduced on the basis of another fact given in reports. In the case of [2, 3], the WISP was used only in the tasks with weak requirements related to data rate issues, in application such a quasi-static deformation analysis, temperature measurements or passive data logging. High values of data rate are rather impossible in this case, due to the setting of measured value into UID, which causes necessity of repeating of reader inventory round for every new portion of data, what strongly elongates data transfer. This feature could be improved by using custom commands similar to these presented in the next report. In the case of [4], the developed CMOS system send 2 bytes of sensing data in one read activity (with two additional 4 bytes related to the calibration data and source information), which value is low in comparison to 128 bytes of sensing data reported in this paper. In the paper [5], there is no any information that could be related to the estimation of the data rate achieved by authors.

To accelerate the data transfer one could develop his own communication algorithm, as it was reported in [9]. Other papers report development of completely new link layer for backscatter communication with many improvements comparing to standard EPC code (For systems working in UHF) [10, 11]. There are also attempts to improve standard anti-collision algorithms by slightly modifying them [12]. In the case of the platform described in this paper, a method that lays between these presented above was chosen. After preliminary investigations, it was obvious, that data transfer should be accelerated, although there was not necessity to develop a new communication layer. Authors have decided to use standard, accessible communication libraries, but with simultaneous development of new software layer of standard RFID reader, as well as using specific data management algorithms on the platforms hardware. The chosen methods allow to achieve data rate sufficient for assumed requirements connected with using designed platform for SHM purposes, especially in tasks, related to structure vibration and strain monitoring with the help of strain gauges and accelerometers.

2 Concept of Sensing Platform

This paper presents a completely new concept of wireless, passive sensing platform. The entire design is based on two main devices. First one is a low-powered microcontroller STM32F051, which is responsible for data acquisition and digitalization. It also controls transfer of data via I2C protocol to the dual-interface EEPROM memory and to the AT45DB ash memory, which states the buffer for large amount of data. The second main element is the dual-interface EEPROM, that possesses communication possibilities via I^2C protocol and via wireless protocol, compliant to standard ISO15693, with typical RFID readers. This element is M24LR64-R chip from ST Microelectronics, which is intended to work in HF band and has memory size of 64 Kbit. For evaluation and investigation purposes, the first design presented on the Fig. 1, has a form of a board with many important signal probes and various powering options and communication interfaces. This allows easy monitoring of signal flow during platform activity and choosing the most efficient components for the final design.

The platform consists of four main parts, which are power supply, analog, communication and supervision circuits. The power supply contains a planar coil antenna tuned to the HF frequency to achieve the best energy transfer between the reader and the sensing platform. Antenna signal is rectified and then conditioned by different elements, operational amplifiers, diodes and inductors. The analog parts consist of an operational amplifier, that amplifies the differential signal from the strain gauge or any other sensor. Next, the signal goes to the analog-digital converter, which is the integral part of the microcontroller. This element, together with the dual-interface EEPROM, is the main part of the communication and supervision sections of the platform. Amplified analog signal from the sensor is converted to digital form and sent to the ash memory. These two processes are capable of executing simultaneously, thanks to the usage of two memory buffers created in RAM memory of the microcontroller. Data from the sensor is gathered in one buffer, while at the same time, the part of data from the second buffer is sent to the ash memory. After overloading of the first

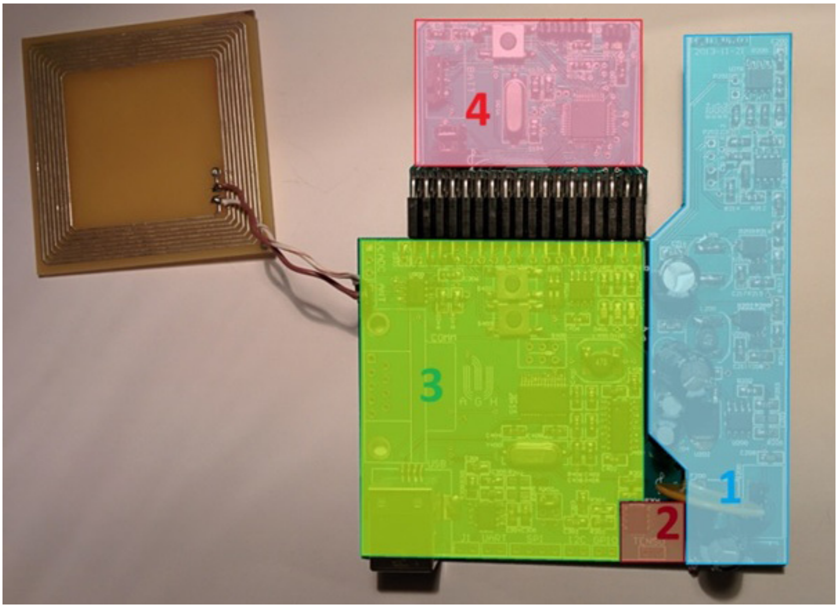

Fig. 1. Evaluation prototype board of wireless sensing platform with four main parts: power supply (1), analog (2), communication (3) and supervision (4) with additional communication planar coil antenna

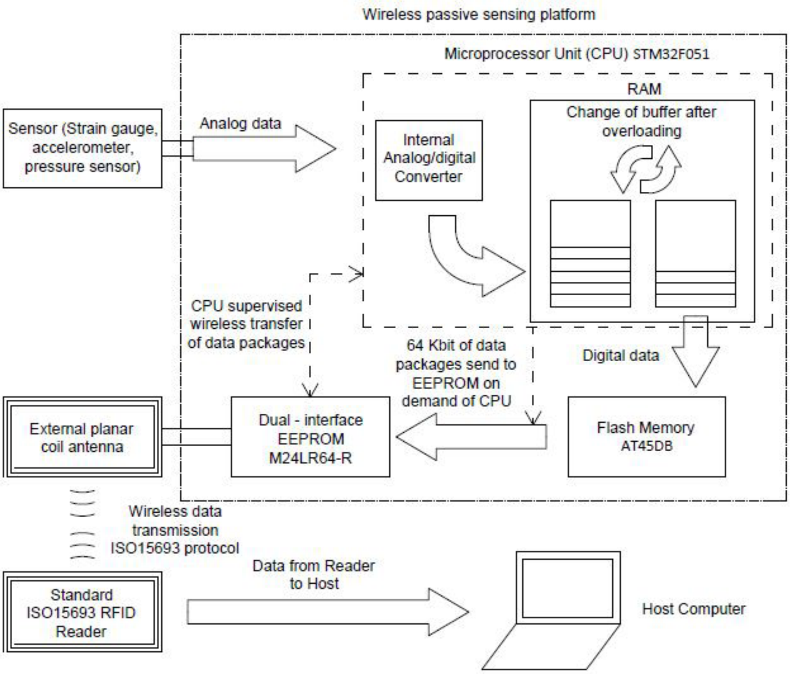

Fig. 2. Data Management process

buffer, their roles turn. This approach allows storing data on the ash memory quasi-directly, where only limitation states capacity of the ash, which in our case is 4 Mbit. Wireless data transfer is also supervised by the microcontroller. Data stored on the ash is divided into 64 Kbit packages and sent to the EEPROM by command of the processor unit. On request of the reader, packages of data are sent wirelessly to the host computer and after completion of this task, a proper signal is sent to the microprocessor from the EEPROM. Whole loop is repeated until all data stored on the ash is sent to the host computer. Entire process of data management is illustrated on the Fig. 2. The communication part also consists of FT232RL and MAX3232CSE, responsible for communication via USB and RS-232 interfaces for the testing purposes. These parts will be excluded in final design.

3 Communication Principles

Problem of communication plays an important role in many wireless data transfer systems. RFID is a technology, where this issue could be considered at different levels. First of all, one could distinguish different layers of communication system, which typically are divided into physical and software layer. This paper brings only fundamental information related to communication issues in RFID passive systems, especially the part that is important for understanding of performed investigations and their reasons. They could be treated only as the tip of the iceberg. For those, who are interested in more complex information, detailed formulas and physical principles of described phenomenon, authors recommend to reference to given sources [13, 14].

The problems related to improvement of communication performance at the physical layer needs wide knowledge and experience in antenna and microwave technology, as well as good basis in theoretical electromagnetic problems. The communication between the reader and the transponder is based on the readers electromagnetic signal reflection by the transponder and the data transfer via impedance modification, according to adopted modulation and coding method. Physical layer is strongly different from the systems based on various frequency ranges. In case of systems operating in LF and HF frequency the antennas of reader and transponder take the form of a planar coil and the contact between them is based on the mutual coupling phenomenon. In this case, important role is played by tuning the planar coil inductance in order to achieve defined frequency resonance and thus maximize the read range. This feature is considered as the most important in different wireless identification systems. In the case of inductive coupled systems, beyond the tuning of antenna, a very important attribute of the antenna is its dimension. Because the read range depends not only on the antenna tuning, but also on the number of magnetic flux lines flowing through the planar coil and on the constant maximal power of the reader antenna that is limited by particular standards, it could be maximized by increasing the transponder antenna size. This is the reason that the engineer, who designs RFID system based on HF frequency range, should always look for trade off between miniaturization and the designed read range, he wants to achieve. Accepted standard is the dimension of the planar coil antenna that corresponds to a typical dimension of a credit card. In case of

UHF systems the communication takes place between the reader and the transponder antenna via the electromagnetic waves reflection. In this case, an important issue is a proper impedance matching between the transponder circuit and the antenna. Generally UHF systems are characterized by a larger read distance, ranging up to 10 meters, but the amount of an energy delivered by the reader is much smaller, than in the case of magnetic coupling. Therefore it is more complicated to base the sensing system on the UHF range (less energy for sensing, data managing and sending of large amount of stored data purposes), although as it was shown in [2, 4], it is not impossible.

The software layer could be considered generally as a readers software section, although a part of this layer is located on the side of transponder chip. It usually is programmed by manufacturer without any possibility to implement changes. The only exception is the system reported in [2], where the standard RFID chip was not used and the role of it is played by a low-powered microcontroller, however this solution is designed for the communication with one particular type of the reader. On the side of the reader, the user could have different access to the software layer depends on the manufacturer. Typically it is ready to use software environment, designed to communicate with transponders and data storing. For users that want to create their own software, there are available libraries with typical commands compatible with particular standard, for instance ISO 15693. These commands, however are the high level instructions. For those, who want to make changes in the core level of the communication, e.g. anti-collision algorithms and management of many transponders reading, they should program the reader on the lower, hardware level, which is not always available for standard users. It should be noted, that standard RFID system is designed for the communication with as many transponders as it is possible in the shortest moment of time and these communication algorithms are not well-suited for the purpose of large amount of data transfer from lesser number of transponders and often, the changes should be introduced on this lower level. The programming part of works reported in this paper was a compromise between difficulty of the access to defined software level and the possibility to achieving better performance.

4 Investigation

The main purpose of investigations reported in this paper was achieving the best data rate, on the way of software improvements and data management optimization. By the way, the authors also estimated the maximal read range of the entire system. Investigations were performed on the evaluation board described in the Section 2. The data rate and the read range was assessed for three different setups. In the first case, the RFID reader equipped with internal antenna, compatible with the ISO 14443 standard with additional emulation that allows communication according to standard ISO 15693. In the second arrangement FEIG OBID ID ISC.MR101-A/USB reader was connected to external antenna, compatible with ISO 15693, supported by the standard software supplied by the manufacturer. In the third case, the same reader was used, but with the software developed by authors, whose nature is described in this section. The role of an exemplary data for sending instead of sensor data, was played by a simulated curve from the signal generator. In each case, the bit rate was checked for the maximal amount of data, that is 64 Kbit, possible to be stored on EEPROM. In case of different readers, the maximal read range was also measured, by connecting the planar coil antenna with the typical credit card dimension, to the sensing platform.

The changes, that improve data rate was introduced, beside the data management algorithm described in Section 2, at the software level of reader. In the standard software, provided by manufacturer, by using multiblock read command, 8 blocks are transferred during one transmission step. It is possible to read 32 blocks at once, provided that they are in the same sector and this change was introduced. This modification is fitted to particular purpose, which is transfer of large amounts of data from one transponder in the range of reader. Additionally, the entire procedure of data transfer is placed in separate thread, what prevents blockade of software operations during reading the data from platform. In the host computer, data is stored in the form of unit16 numbers, what allows for easy export to typical computing environment, for instance MATLAB.

5 Results and Discussion

Achieved results from performed investigations, related to the data rate and the read range are presented in the Tab. 1. They are briefly discussed in this section. In the case of reader compatible with ISO 14443 standard, the short read range is caused by small dimension of the reader antenna and the fact, that it is intended for Mifare standard. The low data rate is the result of incomplete compatibility of reader with the ISO 15693 standard. It supports this standard, by predefined reader commands, which introduce abstraction level, that makes reader more versatile, but at the same time, slower for this specific use. In two next cases, the usage of external reader antenna with larger surface area, allowed to achieve a read range on the level of 30 cm. It makes the sensing platform suitable for assumed applications. The usage of self developed software allows to achieve the best data rate (two times better, than by using standard supplied software), with the value of about 18 Kbit/s. Only that value could correspond with the maximal data rate reported by manufacturer, which is 26 Kbit/s. Making assumption, that this given value corresponds only to the transfer of small amount of data, i.e. UID from transponder, experimentally achieved value seems to be reasonable. It should be noted that the achieved value of data rate corresponds to the entire read range, namely the data rate is independent from the distance between the reader and the platform. It is typical feature of standard RFID systems.

Table 1. Read range and data rate results

Setup	Mifare reader with ISO 15693 emulation	FEIG OBID ID ISC.MR101-A/USB, standard software	FEIG OBID ID ISC.MR101-A/USB, software developed by authors
Read Range	3 cm	30 cm	30 cm
Data Rate	3.5 Kbit/s	9 Kbit/s	18 Kbit/s

6 Conclusions and Future Works

The concept and prototype of wireless passive sensing platform based on RFID technology reported in this paper fits well to many diagnostic and monitoring purposes. Its features place it at the forefront of similar solutions reported in the referenced papers. Preliminary investigations described in this paper concern data transfer purposes. A data management algorithm and the method of wireless data transfer that allow to achieve a bit rate on the level of 18 Kbit/s were presented. Although typical data rate of standard RFID systems could be higher, this is the value related to the transfer of small amounts of data in the form of UID. Information connected with high-volume data transfer are not typically given by the manufacturer. Using RFID chip with EEPROM onboard memory in connection with ash memory that serves as a buffer, allows for easy wireless high-volume data transfer supervised by low-power microcontroller. Achieved read range of 30 cm is also a great advantage compared to different solutions based on HF RFID standard. Performed investigations show, that presented sensing platform could be used in applications related to structural health monitoring of flying objects, especially diagnostic of helicopter rotor blades, as well as in other advanced diagnostic purposes, with the scope on application connected with placing the sensing nodes on moving objects. It needs further investigations related to energy management systems, software optimization and above all application tests performed first in the laboratory and then, on typical exploited objects.

References

1. Lisowski, M., Uhl, T.: RFID based sensing for structural health monitoring. Key Engineering Materials 569-570, 1178–1185 (2013), doi:10.4028/www.scientific.net/KEM.569-570.1178
2. Sample, A., Yeager, D., Powledge, P., Mamishev, A., Smith, J.: Design of an RFID-based battery-free programmable sensing platform. IEEE Transactions on Instrumentation and Measurement 57(11) (November 2008), doi:10.1109/TIM.2008.925019; 2608 RFID based sensing for structural health monitoring 2615
3. Gasco, F., Feraboli, P., Braun, J., Smith, J., Stickler, P., DeOto, L.: Wireless strain measurement for structural testing and health monitoring of carbon fiber composites. Composites. Part A: Applied Science and Manufacturing 42(9), 1263–1274 (2011), doi:10.1016/j.compositesa.2011.05.008
4. Ussmueller, T., Brenk, D., Essel, J., Heidrich, J., Fischer, G., Weigel, R.: A multistandard hf/uhf-rfid-tag with integrated sensor interface and localization capability. In: 2012 IEEE International Conference on RFID, pp. 66–73 (2012), doi:10.1109/RFID.2012.6193058
5. Ikemoto, Y., Suzuki, S., Okamoto, H., Murakami, H., Lin, X., Itoh, H., Asama, H.: Force sensor system for structural health monitoring using passive rfid tags for structural health monitoring. Sensor Review 29(2), 127–136 (2009), doi:10.1108/02602280910936237
6. ISO/IEC 15693 Identification cards – Contactless integrated circuit(s) cards – Vicinity cards
7. ISO/IEC 18000-3:2010 Information technology – Radio frequency identification for item management – Part 3: Parameters for air interface communications at 13,56 MHz

8. ISO/IEC 18000-6:2013 Information technology – Radio frequency identification for item management – Part 6: Parameters for air interface communications at 860 MHz to 960 MHz General
9. Cika, D., Draganic, M., Sipus, Z.: Active wireless sensor with radio frequency identification chip. In: Proceedings of the 35th International Convention MIPRO, pp. 727–732 (2012)
10. Gummeson, J., Zhang, P., Ganesan, D.: Flit: a bulk transmission protocol for RFID-scale sensors. In: Proceedings of the 10th International Conference on Mobile Systems, Applications, and Services, MobiSys 2012 (2012), doi:10.1145/2307636.2307644
11. Zhang, P., Gummeson, J., Ganesan, D.: Blink: A high throughput link layer for backscatter communication. In: Proceedings of the 10th International Conference on Mobile Systems, Applications, and Services, MobiSys 2012, pp. 99–112 (2012), doi:10.1145/2307636.2307646
12. Alma'aitah, A., Hassanein, H., Ibnkahla, M.: Modulation silencing: Novel RFID anti-collision resolution for passive tags. In: 2012 IEEE International Conference on RFID (2012), doi:10.1109/RFID.2012.6193060
13. Finkenzeller, K.: RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification, 2nd edn. Wiley (2003), doi:10.1002/9780470665121
14. Lehpamer, H.: RFID Design Principles, 2nd edn. Artech House Publishers (2012)