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A Configurable RFID Sensor Tag Baseband Conforming to IEEE 1451.7 Standard

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Abstract

This paper presents a design of sensor tag baseband based on IEEE 1451.7 standard. In this work, general UHF RFID commands is implemented by the hardware state machine in baseband and an embedded 8-bit microcontroller is adopted to process IEEE 1451.7 standard. The simulation and test results show that this design is able to realize the IEEE 1451.7 standard with high flexibility. The power consumption of the baseband is about 18μW at the clock frequency of 1.28MHz and 1.2V power supply, which is suitable for RFID sensor tags and portable application.

1. Introduction

Radio-frequency identification (RFID) is a wireless non-contact system using radio-frequency electromagnetic fields to transfer data from a tag attached to an object for the purposes of automatic identification and tracking. Two of the main applications of UHF RFID in logisticsare warehouse management and transportation management. Traditionally, tags are attached to items in supply chain for the purpose of identification, monitoring, and security. However, in some cases, not only the serial code but also the status of the items needs to be acquired, like the temperature of yogurt. This leads to the idea of integrating sensors with RFID tags, which would enable the RFID system with the ability of perceiving the external environment, thus giving birth to many new applications in IoT in agriculture, logistics, and warehouse management. Tags armed with sensors can detect physical variables such as temperature and acceleration and can store their history values in tags' memories. These data can be retrieved by RFID Readers and help determine if the items have experiencedunfavorableconditions. The potential application fields include logistics, cold-chain management, and storage, which all require tracking of status and long communication distance. So, the suited RFID protocol is EPC Gen2 protocol [1]. The Gen2 protocol was accepted as the ISO 18000-6C [2] standard by ISO/IEC.

Recent study of RFID sense mainly focuses on low-power on-chip sensor designs[3][4][5], but the data formats and sensor configurations are not flexible enough to be applied in various scenarios. Some RFID sensor tag designs that support data logger have been released [6][7][8]. However, sensor management methods vary in different sensor tags, and there are many proprietary communication protocols for sensors RFID system. The non-interoperability between different products will limit the development of RFID sensing. To deal with this issue, IEEE 1451.7 has been released in 2010 [9]. IEEE 1451.7 specifies a transducer to RFID Systems Communication Protocols and Transducer Electronic Datasheet (TEDS). It also defines many data structures and commands to configure and operate sensors.

This paper presentsa design and implementation of the hardware and software architecture of a sensor tag digital baseband, which complies with the ISO 18000-6C (EPC Gen2) protocol and can conduct smart sensing according to the IEEE 1451.7 standard. In part II, the communication process in ISO/IEC 18000-6C and IEEE 1451.7 protocols is analyzed; in part III, the architecture of the baseband design is introduced; in part IV, detail information about the means to support IEEE 1451.7 is presented; implementation results are shown in part V; and part V concludes the paper.

2. Protocol Analyses

2.1. ISO/IEC 18000-6C

ISO/IEC 18000-6C (EPC Gen2) is a widelyaccepted standard for UHF RFID air interface. The support of sensor and battery-assisted-passive (BAP) RFID system is added in the latest version. A tag that supports a sensor should transmit its XPC_W1 (Extended Protocol Control) after PC when replying to an ACK command to indicate the support of the sensor. In the chapter Sensor support, this standard defines two classes of sensor: Simple Sensor and Full Function Sensor. The Full Function Sensor is more flexible and configurable. The characteristics and capabilities are given in the IEEE 1451.7 standard. ISO 18000-6C also defines the HandleSensor command to provide the means to support a broad range of different sensors types and hence different command sets. The HandleSensorcommand shown in Table I [9]provides a transport mechanism to carry commands for intelligent sensors as a payload.

	Command	PortNr	Payload Size	Payload	Response Expected	Response Length	RN	CRC-16
# of bits	8	7	Variable	Variable	1	Variable	16	16
Description	11011001	Logical sensor address	Length of the Payload (EBV.8)	Sensor command	1=true 0=false	Expected length of the sensor response	Handle	

Table 1: STRUCTURE OF HANDLESENSOR COMMAND

	Header	Response	RN	CRC-16
#of bits	1	Variable	16	16
Description	0	Sensor response	handle	

Table 2: TAG REPLY TO SUCCESSFUL HANDLESENSOR COMMAND

The response of HandleSensor command is shown in Table II [9] and shall begin within 20ms after the tag receives a HandleSensor command with correct handle and crc16. Compared with T1 (usually tens of μs) timing requirement, HandleSensor command does not require a strict reply timing.

2.2. IEEE 1451.7

IEEE 1451.7 belongs to IEEE 1451 serials of smart transducer standards. It was accepted by ISO/IEC as ISO/IEC/IEEE 21451-7 standard in 2011 without much modification. In this paper, it is still referred as 1451.7 for short.

IEEE 1451.7 introduces four primary data structures (Table III)[10], each consisting of multiple elements.

Data Structure	Description
Primary Sensor Characteristics TEDS	● Registers tag properties. ● Unchangeable after the tag has been manufactured ● Typical element of the structure: ● sensor data resolution
Sample and Configuration Record	● Registers pre-sensing properties ● Configured by the RFID reader before sensing ● Typical element of the structure: ● sample interval time
Event Administration Record	● Registers post-sensing status ● Updated when the sensing is done ● Typical element of the structure: ● count of sampled datavalues
Event Records	● Sensing data record includes data log, data statistics, and filtered data log

Table 3: IEEE 1451.7 DATA STRUCTURE

IEEE 1451.7 introduces a command set to facilitate communication between RFID systems and RFID sensor tags. It consists of 21 commands in six categories. The most useful command categories are the read class and the write class. A typical communication between RFID Reader and sensor tag that transfers sensor data is described in Fig. 1.

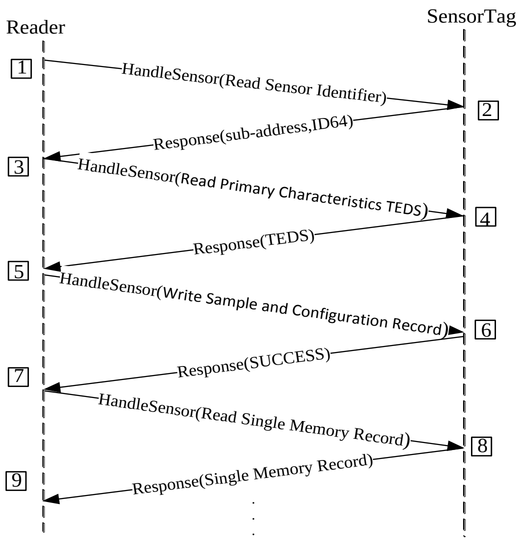


Fig. 1: Typical IEEE 1451.7 communication process

3. Architecture

The digital baseband of anRFID sensor tag is used to process signals from the RF frontend, the memory and the sensor, and to control the tag’s states and operations. A sensor interface, protocol processor, RTC and memory interface should be contained in it. A digital baseband based on state machine could realize all functions mentioned above, but this approach disables the sensor tag system to be applied to various scenarios. This is mainly caused by the diversification of sensors. The types, data resolution, and operating sequence varies in different sensors, thus a sensor driver based on FSM (finite-state machine) cannot be easily adjusted to fit various sensors: adding new features or exchanging the sensor will result in long development cycles. Another consideration is from the IEEE 1451.7 protocol itself. IEEE 1451.7 supports a great many configuration parameters and a sensor tag may support multiple measurement types that need complex data processing, such as maximum value, average value and standard deviation. A hardware FSM implementation may be quite complex and large. However the data management with software is relatively simple. So the architecture incorporating a microcontroller and a Gen2 protocol processor is adopted in this work, as shown in Fig. 2.

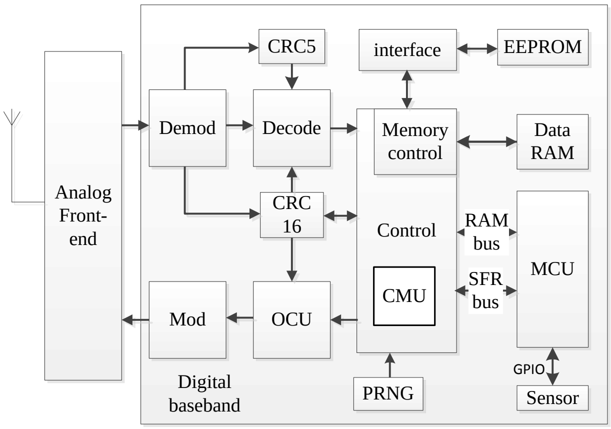


Fig. 2: Sensor tag architecture

The sensor tag digital baseband can be mainly divided into two parts: RFID core module and MCU. The RFID core module provides a reliabledata link and process ISO 18000-6C commands: the DEMODE module demodulates signals encoded in pulse-interval encoding (PIE) format from the analog frontend; the DECODE module decodes the signals to recognizable commands and data; the CRC module is used for Cyclical Redundancy Check to ensure that there is no error bits when data transmitting; the output control unit (OCU) controls the output data and passes data to the MOD module; the MOD module modulates backscattering data into FM0 or Miller format.

The MCU provides sensor interface and processes IEEE 1451.7 commands. The MCU interacts with the RFID core module by SFR (special function register) bus and data RAM. To reduce chip area, only an 8-bit GPIO port is implemented as sensor interface. Users can attach any sensor that can output digital signals to the tag using a specified driver program.

A microcontroller based sensor tag can be used in various application scenarios, and the main advantage is high flexibility. In this design, when powered-up, the tag will load program code (firmware) from the EEPROM to the MCU's program memory (implemented as RAM). The firmware can be easily changed through standard WRITE command. Thereforethe sensor tag can be user-programed and can be used in different monitor applications.

To optimize power consumption, a clock management unit is embedded in the RFID core module. Usually, all the modules do not work simultaneously. For example, when a tag is decoding, the MOD module does not need to work. So the gated clock technology is employed to reduce the leak current of the registers.

4. IEEE 1451.7 support

As mentioned above, the MCU mainly deals with IEEE 1451.7 standard. Since the timing constraint is not strict, clock frequency can be low enough to save power. In this design a 1.28MHz clock is used as the main clock, just same as the RFID core module. The MCU adopted in this sensor tag baseband is an 8051-compatible MCU –DW8051 [11]. It is configured with two timers, one parallel port and one serial port.

4.1. IEEE 1451.7 commands support

All of the IEEE 1451.7 commands are encapsulated into the HandleSensor command. The process sequence of a HandleSensorcommand is described as below:

4.1.1. Parse the Handlesensorinstruct

The DECODE module receives every single field of the command and writesPortNr, Payload Size, Response Expected and Response length to SFRs. The payload (main body of IEEE 1451.7 command) is written to data RAM (Fig. 3). Then the control module gives an interrupt signal to the MCU.

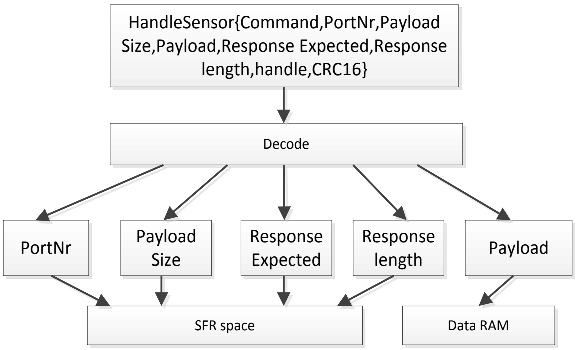


Fig. 3:HandleSensor command decode

4.1.2. Execute commands in interruptroutine

The MCU gets the payload from data RAM, parses the IEEE 1451.7 command, executes the command, then writes response data to another RAM area (Fig. 4) and finally gives a "done_mcu" signal to the control module.

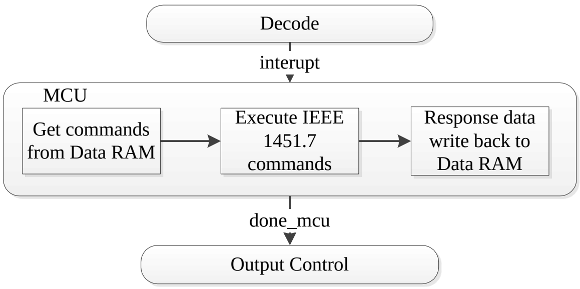


Fig. 4: IEEE 1451.7 command executes sequence

4.1.3. Output response data to analog frontend

The OCU module firstly sends the header and then sends bits of Response length from data RAM.

In the current version, the design does not support any security related commands like key write, security set up, security control, and special cases commands.

4.2. Sensing support

4.2.1. Sensor

Any kind of sensors can be adopted in this design. In current version, a commercialtemperature sensor LM75A [Philips Semiconductors, LM75A datasheet [M], 2004] with an Inter-Integrated-Circuit (I^2C) interface is adopted as an example for testing.

4.2.2. Sensor driver

The sensor LM75A is attached to the parallel port of the sensor tag. The software simulation method is used to simulate the I^2C interface. The sensor is configured and operated according to the LM75A's datasheet by the simulated I^2C interface; thus, the temperature value can be obtained. One of the two timers in DW8051 is used as an RTC. It will interrupt every 0.5 seconds, so the tag can receive the current time. When the sensor tag is configured, the MCU will begin sense according to the Sample and Configuration Record.

5. Implementation Results and Test

The sensor tag baseband is synthesized by the Synopsys Design Compiler in the SMIC0.13μm process cell library, and the area of each module is noted Table IV.

Module	Area(μm^{2})	Equivalent gate	Rate
DW8051_core	55338	11k	39.6%
P1	642	126	0.4%
CONTROL	55600	11k	39.8%
DEMOD	6465	1269	4.6%
DECODE	8025	1576	5.7%
OCU	2997	588	2.1%
MOD	606	119	0.4%
PRNG	1699	334	1.2%
CRC	760	149	0.5%
EEINTERFACE	2916	573	2.0%
SFR	4434	871	3.2%
total	139663	27k	100.0%

Table 4: AREA CONSUMPTION OF EACH MODULE

The Synopsys power simulation toolNanoSim is used to evaluate the power consumption of the digital baseband. NanoSim can simulate the power with the netlist generated by Design Compiler under user defined test stimulus. Line 5 of the simulation waveform is the test stimulus and line 8 is the MOD module output. From left to right, the baseband received commands encoded in PIE format: Query→ACK→ReqRN→HandleSensor (Read-Sensor-Identifier, Parameter=0)→HandleSensor (Write-Sample-Configuration)→HandleSensor (Read-Single-Memory-Record)→HandleSensor (Read-Sensor-Identifier, Parameter=1)→ Read→ReqRN→Write. As we can see, the tag baseband executes all the commands properly. Simulation result shows that the average current is about 15 μA when the support voltage is 1.2V and clock frequency is 1.28MHz (Fig. 5). If a sensor tag supports adata logger, it should be powered by a battery. If it uses AG13 button cell (140mAh, 1.5V) as a power supply, the tag can work for about 1 year.

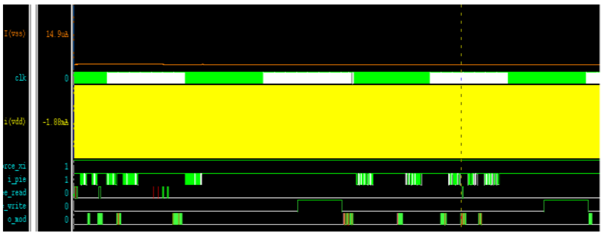
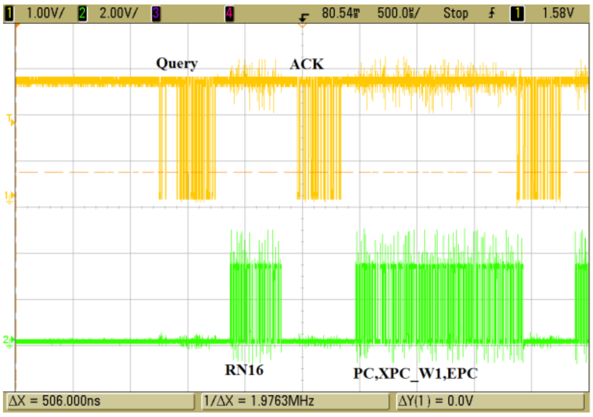
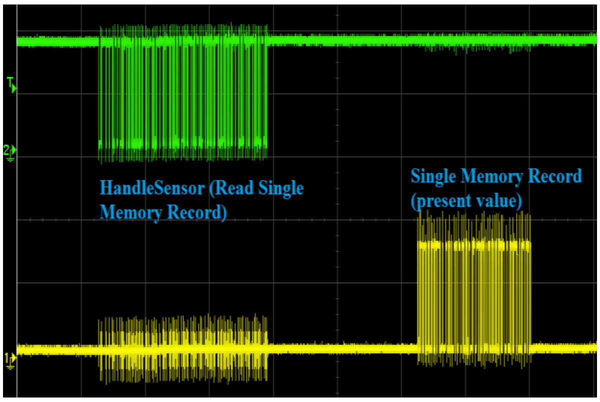


Fig. 5: NanoSim simulation result

The design is verified by FPGA board. Figure 6 (a) shows that in an Inventory round, the tag response with XPC_W1 indicating that it has a sensor. Figure 6 (b) shows a HandleSensor command which contains IEEE 1451.7 Read-Single-Memory-Record command and its response. It is indicated that the digital baseband can process IEEE 1451.7 commands properly and the architecture is feasible.



(a)



(b)

Fig. 6: FPGA test results

6. Conclusion and future work

In this paper a reconfigurable and extensible sensor tag digital basebandis designed and implemented, which could interact withReader by HandleSensorpackagedIEEE 1451.7 command and couldcontinuously store and transport sensing parameters according to IEEE 1451.7.The area consumption is 27 Equivalent gates and power consumption is about 18μW at a clock frequency of 1.28MHz when the supply voltage is 1.2V. The digital basebandis suitable for RFID sensor tags.

Future works based on the current design may include supporting security related commands with an encryption engine and support for multiple sensors.

References:

[1] EPCglobal, “EPC Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz -960 MHz Version 1.2.0” [S], 2008

[2] ISO/IEC, “Radio frequency identification for item management -- Part 6: Parameters for air interface communications at 860 MHz to 960 MHz” (ISO18000-6) [S]

[3] H. Reinisch, M. Wiessflecker, S. Gruberet al. “A Multifrequency Passive Sensing Tag With On-Chip Temperature Sensor and Off-Chip Sensor Interface Using EPC HF and UHF RFID Technology” [J], Solid-State Circuits, IEEE Journal of , vol.46, no.12, pp.3075-3088, Dec. 2011

[4] D. Yeager, Zhang Fan, A. Zarrasvandet al. “A 9.2µA gen 2 compatible UHF RFID sensing tag with −12dBm Sensitivity and 1.25µVrms input-referred noise floor” [A], 2010: 52-53

[5] M. Guerin, P. Lauque, E. Bergeretet al. “A temperature and gas sensor integrated on a 915MHz RFID UHF tag” [A], 2010: 1-4

[6] Alanson P. Sample, Daniel J. Yeager et al., “Design of an RFID-Based Battery-Free Programmable Sensing Platform”, IEEE Transactions on Instrumentation and Measurement, vol. 57, no. 11, Nov. 2008

[7] Productivity Engineering GmbH, “PE3001 UHF-RFID Sensor Data Monitoring IC”, http://www.pe-gmbh.com

[8] Ralf Hildebrandt, Michael Heiss, Nicolas Gay, “A Smart ISO 18000-6C RFID Sensor Tag Platform” [A], RFID SysTech 2011

[9] IEEE 1451.7, “Standard for a Smart Transducer Interface for Sensors and Actuators–Transducers to Radio Frequency Identification (RFID) Systems Communication Protocols and Transducer Electronic Data Sheet Formats”, IEEE Instrumentation and Measurement Society, TC-9, The Institute of Electrical and Electronics Engineers, Inc.(2010)

[10] Feibai Zhu, Min Li, Haichao Han, and Junyu Wang, “RFIDsense: a Reconfigurable RFID Sensor Tag Platform Conforming to IEEE 1451.7 Standard”, ASIC (ASICON), IEEE International Conference on, 2011

[11] Synopsys. “DesignWare DW8051 MacroCell Databook” [R]