Design of UHF RFID Baseband Chip with Temperature Sensing

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Abstract. The radio frequency identification (RFID) with temperature sensor can achieve accurate management and body temperature measurement in animal husbandry. It also can improve the efficiency and epidemic prevention. A ultra high frequency (UHF) RFID chip baseband integrated with a specific temperature sensor is designed compliant with “Information Technology Radio Frequency Identification 800/900MHz Air Interface Standard” (GB/T 29768). Firstly, according to the overall function, the unit division and structure design of digital baseband are given. Secondly, a baseband temperature sensor control unit connected with temperature sensor is proposed. Finally, the whole function simulation and experiments on FPGA are completed. The experimental results show that the designed UHF RFID baseband can satisfy the communication of both sides and realize the interaction with the temperature sensor.

1. Introduction
Radio frequency identification (RFID) is a rapidly developing automatic identification technology that can realize the identification, tracking and management of items[1-3]. No human intervention is required under non-contact conditions. It can recognize multiple high-speed moving objects at the same time. The operation is fast, simple and convenient. Electronic tags are not affected by harsh environments such as dust and smoke, and are not easily to be damaged[4-5]. The combination of RFID technology and various sensors can realize environmental monitoring, health monitoring and other applications. Real-time traceability of project information and timely sharing of information are made possible[6-7].

Body temperature is an important manifestation of animal sign information. Applying RFID technology to the monitoring of livestock body temperature can achieve the purpose of efficient epidemic prevention. This can increase the value of livestock and reduce animal mortality. The current design of RFID tag chips is mainly based on the EPC Class1 Generation 2 Standard (EPC C1G2). There is a design that uses the Write command to control the temperature sensor. However, in this method, the obtained temperature data cannot be fed back to the reader directly. Instead, it needs to be
kept in memory and then obtained through the Read command. This process requires reading and writing to memory, which is a complex process that takes a long time[8]. There are also designs that use the Ack command to get the temperature data. When the digital baseband judges that the Ack command is valid, the control unit starts the temperature sensor to work. The baseband included the data measured by the temperature sensor in the response package of the Ack command and coded it back to the simulation front end[9]. This method is relatively simple, time-consuming and low power consumption.

GB/T 29768 Information Technology Radio Frequency Identification 800/900MHz Air Interface Standard (GB/T 29768) is an improvement on EPC C1G2[10]. This paper is based on GB/T 29768 standard. After initialization the baseband reads the tag identification information (ID) and temperature calibration parameters in the memory, where ID is used to uniquely identify individual information and temperature calibration parameter is used for secondary calibration of temperature data. When the baseband is in response, acknowledgement, open or secure state, the master control unit determines whether the Ack command received is valid or not. If the command is valid, the baseband controls the temperature sensor to measure the temperature. The calibrated temperature data and ID information are placed in the response package of the Ack command and encoded back to the reader.

2. GB/T 29768 standard

Ultra high frequency (UHF) RFID technology coexists with a variety of standards throughout the world and a unified global standard has not been formed. Currently, the most widely compatible agreement internationally is the EPC Global organization that makes EPC C1G2. GB/T 29768 standard is an improvement on the basis of EPC C1G2. The main differences are as follows:

- The forward coding is different: The truncated pulse position encoding (TPP) requires less system bandwidth than the pulse interval encoding (PIE). This method not only improves the ability of readers to provide energy to passive electronic tags, but also enables forward links to achieve higher code rates at the same bandwidth, which has great practical significance.

- Collision prevention mechanism is different: The EPC C1G2 standard adopts the time slot random collision prevention algorithm. The GB/T 29768 standard adopts the dynamic shrink binary tree mechanism. Compared with the EPC C1G2 standard, the identification time is shortened, the tag recognition rate is improved, and the collision prevention effect is better[11].

- The users of the storage is different: The tag memory user area designed based on the EPC C1G2 standard can be at most one, while the tag user area can be divided into multiple based on GB/T 29768. Each sub-area has an independent access password, which means that a tag can identify multiple items at the same time and adapt to the application of ring mirror in multiple scenes.

- Security encryption is different: The GB/T 29768 standard supports two-way security identification between reader and tag. Its data transmission adopts the encryption mode of SM7 to ensure the security of data and prevents information leakage and tampering. The operation is not supported by the EPC C1G2 standard.

GB/T 29768 standard specifies the air interface parameters in the RFID system of the physical layer and media access control layer and the working mode of the standard. The frequency bands are 840MHz-845MHz and 920MHz-925MHz. Half duplex communication is used between readers and tags[12]. In communication, the reader sends the command first. The tag performs the corresponding operation and sends the response package as needed. Readers use TPP encoding and double-sideband amplitude shift keying (DSB-ASK) or single_sideband amplitude shift keying (SSB-ASK) for debugging radio frequency (RF) carriers to send the commands to one or more tags. After that, readers continue to send the unmodulated RF carriers and listen for the response packages from the tags. Tags get working energy from the RF carriers and encode the baseband data using the Bi Phase Space Coding (FM0) or Miller coding. The communication flow between reader and tag is shown in figure 1. The command function is shown in table 1.
Figure 1. The communication flow between reader and tag.

Table 1. Required command function.

| Bas⁴ Command | Function | Bas⁴ Command | Function |
|--------------|----------|--------------|----------|
| 0000b Sort   | Changes to the matching flag or check mark in the tags. | 1000b RefreshRN | It can get a new handle. |
| 0001b Query  | An inventory cycle is initiated, which also specifies the preamble information, the reverse link rate factor and the coding selection. | 1001b get_RN | It can get a 16-bit random number from the tag. |
| 0010b QueryRep | The value of the slot can be updated. | 1010b Access | It can open permissions. |
| 0011b Divide | The tags can be split. | 1011b Read | It can read data from the tag logical memory area. |
| 0100b Disperse | It can scatter tag. | 1100b Write | It can write data to the tag logical memory area. |
| 0101b Shrink | It can shrink the tag. | 1101b Erase | It can erase data from the tag logical memory area. |
| 0110b ACK | It can get the code area data. | 1110b Lock | It can lock the security mode of the tag logical storage area or configuration tag. |
| 0111b NAK | It can indicates that the tag responds incorrectly. | 1111b Kill | Tag inactivation. |

* Bas refers to binary command code.

3. Design and implementation of baseband

3.1. Overall architecture design

In this design, the overall function of the digital baseband is divided into 11 units, as shown in figure 2. The detailed description is as follows:

- Initialization unit (INIT): The tag is initialized.
- Decoder unit (DECODER): TPP decoding the demodulated data received from the analog front end.
- Command parsing unit (CMD): Parsing of each command is completed. There are 16 mandatory commands involved in this design.
- State control unit (SCU): This unit is the core of the entire baseband, which is responsible for implementing primary state jump of the tag, controlling the tag data reflection type, generation and update of slot values (slot_val). Almost all the units operate with the states generated by the SCU unit. *_open signal represents the control of each unit by the SCU. * is the total number of units that can be controlled.
- Random number generation unit (RNG): Random numbers and handles are generated and updated.
- CRC unit (CRC): CRC16 checks, CRC5 and CRC16 calculations are performed.
- Output control unit (OCU): The response package is encoded and output to the reader.
- Divider unit (DIV): The system clock is divided to get the required clock for each unit.
- EEPROM interface management unit (IE): The data interaction between baseband and the EEPROM is responsible by this unit.
- Power management unit (PMU): The working states of each unit is managed.
Temperature sensor control unit (TSCU): The interface between the baseband and the temperature sensor is implemented. The temperature data is calibrated through this unit.

![Digital baseband structure of RFID temperature sensitive tag chip.](image)

This design adopts the multi-clock domain design scheme to reduce power consumption. The system clock is 1.28MHz. Public clocks are `tpp_clk`, `DOUBLE_BLF` and `data_clk`, where `data_clk` includes `BLF`, `HALF_BLF`, `FOURTH_BLF` and `EIGHTH_BLF`. `BLF` is the reverse link frequency. The frequency of `DOUBLE_BLF` is twice that of the `BLF` clock. `HALF_BLF`, `FOURTH_BLF` and `EIGHTH_BLF` are `BLF` divided by 2, 4 and 8.

The `tpp_clk` is generated by the `DECODER` unit. One TPP clock pulse corresponds to one TPP decoded data. `DOUBLE_BLF` is generated by the `DIV` unit, which is the working master clock of most units in the digital baseband. `INIT`, `PMU`, `SCU`, `CRC`, `RNG`, `IE`, and `TSCU` units are all controlled by this clock. The `data_clk` is used to control the reverse data rate of the tag.

3.2. Design of the state machine
The state transition diagram of the main state machine is shown in figure 3. According to the standard requirements and design requirements, the design involves seven states. The relevant design description is as follows.

- **READY state**: Electrified and not inactivated tags enter the READY state.
- **ARBITRATION state**: When the `QueryRep`, `Divide`, `Disperse` or `Shrink` command is received in the ARBITRATION state and `slot_val` is 0, the tag jumps to the REPLY state. Otherwise it jumps to the READY state when the `Sort` command is received.
- **REPLY state**: After the `Query` command is matched, the tag jumps to the ACK state and a response package can be sent. In the event of collision, reader sends `Divide`, `Disperse` and `Shrink` command to make part of the tags entering the ARBITRATION state.
- **ACK state**: After the `Ack` command is completed, the tag jumps to the ACK state. When the tag does not receive any commands within `T2` time range, it jumps to the ARBITRATION state automatically. `T2` represents the time between the end of one command on the tag and the next command from the reader.
- **OPEN state**: After the `Get_RN` or `RefreshRN` command is received, the tag jumps to the OPEN state.
- **SAFE state**: The `Access` command is executed in the OPEN state and the handle and password are correct. Then the tag jumps to the SAFE state. In this state, it can perform the inactivation operation.
• **KILL state**: The tags in the KILL state cannot respond to any command and this state cannot be changed.

![Figure 3. The state transition diagram of the main state machine.](image)

3.3. **Temperature sensor control unit design**

The digital code $D_{out}$ sent by the temperature sensor is received through the TSCU unit, which is linearly correlated with the temperature $T_{out}$. That is $T_{out} = AD_{out} + B$, where $A$ is gain coefficient, $B$ is migration.

| Ideal temperature/°C | Data code | Error/°C |
|-----------------------|-----------|----------|
| 36                    | 00011100011<sub>b</sub> |                      |
| 37                    | 00100001011<sub>b</sub> |                      |
| 38                    | 00100110100<sub>b</sub> |                      |
| 39                    | 00101010100<sub>b</sub> |                      |
| 40                    | 00110000000<sub>b</sub> |                      |
| 41                    | 00110100110<sub>b</sub> | ±0.1°C               |
| 42                    | 00111001011<sub>b</sub> |                      |
| 43                    | 00111100001<sub>b</sub> |                      |
| 44                    | 01000001011<sub>b</sub> |                      |
| 45                    | 01000111101<sub>b</sub> |                      |

Assuming the calibration is carried out at $T_1$ and $T_2$ temperature and the corresponding digital codes are $D_{out1}$ and $D_{out2}$ respectively. $D_{out}$ and $D_{out2}$ are temperature calibration parameters that are stored in memory when the chip is set in factory. Since 37~42°C is the temperature range of common animals, 37°C and 42°C are selected as the temperature calibration parameters. One temperature measurement procedure is finished when $t_{done}$ is high, 16 temperature measurements can be received. First, the temperature measurements are averaged 16 times by the TSCU unit. Then the averaged data is calibrated at two points to get the final value of 11-bit. The integer part is the higher 6-bit, the last 5-
The temperature sensor is shown in Fig. 2. Experimental results on FPGA. The 11-bit represents the decimal part. Its minimum resolution is 0.031°C. The data codes corresponding to temperature values received once are shown in table 2.

The interface design of the digital baseband and the specific temperature sensor is shown in Fig. 2. When the baseband is in the \textit{REPLY}, \textit{ACK}, \textit{OPEN} or \textit{SAFE} state and the \textit{Ack} command is valid, the enabling signal \textit{tscu_en} of the \textit{TSCU} unit is converted to a higher level by \textit{PMU} unit. The \textit{TSCU} unit starts working.

An enabling signal \textit{sen_en}, a reset signal \textit{sen_rst}, a voltage set signal \textit{sen_vst} to the temperature sensor, the final temperature value \textit{t} to the \textit{OCU} unit, and a temperature measurement completed signal \textit{tscu_done} to the \textit{PMU} unit are provided by The \textit{TSCU} unit. This unit can also receives at a time conversion completion flag \textit{sen_done}, the 16 times conversion completion signal \textit{sen_cnt16}, and the temperature data \textit{sen_data}. The important ports are defined as follows:

- \textit{sen_en}: The temperature sensor is turned on for temperature measurement.
- \textit{sen_rst}: It is the reset information of temperature sensor, which is high level active.
- \textit{sen_vst}: The voltage across the capacitor is pulled high and the low level is valid.
- \textit{sen_done}: It represents the completion signal of a single temperature measurement.
- \textit{sen_data}: The average value is obtained for 16 times of temperature measurement.
- \textit{sen_cnt16}: It represents the completion of 16 times temperature measurements.
- \textit{tscu_done}: When the temperature acquisition is completed, \textit{TSCU} unit outputs \textit{tscu_done} as a high level to the \textit{PMU} unit.

4. Experimental results and analysis

4.1. Implementation of temperature sensor control unit

RTL-level test of the baseband overall function is simulated on ModelSim. At this stage, the \textit{read.v} file is used to represent the received reader signal after parsing and processing of the RF analog front-end. First, the tag receives the system reset signal \textit{rst_n} as 0, which indicates that the tag has entered the reader's RF field. After that, \textit{rst_n} returns high. Then the commands in the order of \textit{Sort}, \textit{Query}, \textit{QueryRep}, \textit{Divide}, \textit{Disperse}, \textit{Ack}, \textit{Query}, \textit{Ack}, \textit{Get_RN}, \textit{Access}, \textit{Write} are sent by the reader. \textit{scu_state} indicates the state of the main state machine, which corresponds to entering \textit{READY}, \textit{REPLY}, \textit{ARBITRATION}, \textit{REPLY}, \textit{ACK}, \textit{OPEN} and \textit{SAFE} states in order. The corresponding response packages according to the standard are sent by the tag. When the tag is in the \textit{REPLY}, \textit{ACK}, \textit{OPEN} or \textit{SAFE} state and the command conditions are valid, the \textit{Ack} command can be responded and the response package of \textit{Ack} can be sent. The 11-bit temperature measurement and its ID are included in this package. In the experiment, the first \textit{Ack} command is not answered because the tag is in the \textit{ARBITRATION} state. RTL coding simulation results of tag digital baseband is shown in figure 4.

4.2. FPGA verification

Sections should be numbered with a dot following the number and then separated by a single space:

In this stage, the HDL code is loaded into the FPGA development board through the QuartusII platform. The FPGA development board used in this experiment is ALTERA Cyclone IV. The I/O ports in the top-level unit are pin configured and mapped to actual hardware circuits. The \textit{order.v} file is designed to control the command sent by the reader. In this file, the signal \textit{start} is used to do this. The hardware interface of \textit{start} is connected to \textit{Key1} of FPGA. The high level is valid. \textit{read_rst} controls the reset of the reader and its hardware interface is connected to \textit{Key2}. Active at high level. The output signal is connected to the hardware \textit{UartSend}. As well as the system clock and system reset signals are connected according to the schematic diagram.

After the hardware interface is connected, the online logic analysis tool Signaltap is used for functional debugging and verification of the digital design. Figure 5 is experimental results on FPGA board. When the \textit{Ack} command is executed for the second time, the temperature measurement obtained is 10011110100. The result is correct within the error range. Instruction execution proves that the program can run effectively on hardware.
Figure 4. RTL coding simulation results of tag digital baseband.

Figure 5. Experimental results on FPGA board.

5. Conclusion
Under the premise of compatibility with GB/T 29768 standard, the baseband system structure and unit division of tag chip with temperature sensor are proposed. Also the function simulation of baseband circuit and FPGA hardware verification are realized. Experimental result shows that the designed baseband can process the required commands in the standard and execute corresponding actions in different states. The correct transitions in READY, ARBITRATION, REPLY, ACK, OPEN, SAFE and KILL states can be performed by the main state machine. The communication and interaction between baseband and temperature sensor can be realized through the TSCU unit. Finally, the calibrated temperature measurement combined with its ID can be returned to the reader through response package of Ack command. The experimental results show that this baseband can be integrated with the temperature sensor in addition to the general functions. But the actual chip integration is not complete yet, so the data is just a simulation. The actual temperature test can only be done after the chip is posted.

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