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Research and Implementation on Networked Smart Sensor Based on IEEE1451 Standard

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Abstract: Firstly, the background and significance of IEEE1451 standard are introduced. Secondly, each protocol, especially the IEEE1451.2 standard of IEEE1451 family standards, is described respectively, including Smart Transducer Interface Module(STIM), Network Capable Application Processor (NCAP) and Transducer Electronic Data Sheet(TEDS). Then, a new design idea and implementation of a kind of networked smart sensor based on the IEEE451.2 is introduced in detail. Finally, the advantages and trends of the smart sensor based on IEEE1451 standard are summarized.

Keywords: IEEE1451, Smart Transducer Interface Module(STIM), Network Capable Application Processor(NCAP), Transducer Electronic Data Sheet(TEDS), networked smart sensor.

1. INTRODUCTION

The sensor is the general term of the information acquisition devices, and often used to convert various measurements into electric quantities, it is an essential part to acquire input signals for kinds of monitoring technology system. As the development of communication technology, computer technology, semiconductor technology and network technology, the sensor technology is walking to the direction of becoming more networked and smart which making a continuous improvement of networked monitoring technology. Compared with the traditional sensor, smart sensor not only has the function of information collection, but also has a certain ability of self checking, self compensation, analysis, judgment and two-way communication. What's more, the precision of measurements also have improved in a sense. In the monitoring network, applying field-bus technology to sensors can reduce the connection and bandwidth between the sensors and the main control system effectively, and it realized the intelligence distribution as well. This kind of communication smart sensor is also thought to be networked smart sensor. Currently, monitoring network uses various of communication protocols, such as CAN bus protocol, RS232 communication, RS485 protocol, USB interface protocol, one - wire protocol, TCP/IP protocol and so on. The protocol conversion is often required when we connect sensors to the network. In order to solve this problem, we need a common sensor interface protocol [1].

IEEE1451 is an open standard of smart sensor interface protocol suit, used for unified the interface protocols between sensors and different network. Starting in September 1993, the American national standards institute of technology and IEEE association of sensing technical committee jointly organized to formulate a common smart sensor communication interface protocol and related standards. Later in 1995, two standers named IEEE1451.1 and IEEE1451.2 passed. Then IEEE1451.3, IEEE1451.4 and IEEE1451.5 standard successively passed. In recent years, IEEE1451 standard is still in continuous improvement and perfection.

Among IEEE1451 protocol suit, the IEEE1451.2 is more often used, the IEEE1451.2 standard mainly defines the transducer electronic data sheet TEDS (Transducer Electronic Data Sheet) and the digital interface standards, which includes the communication interface protocols and the pin definitions between smart transducer interface module STIM (Smart Transducer Interface Module) and network capable processor NCAP (Network Capable Application Processor), it is a practical Interface standard [2].

Combing IEEE1451 standard with smart sensors make sensors not only have smart function but also have a common network communication interface. So as to solve the problem of the sensors' disagreement in network interface, and this is networked smart sensors based on IEEE1451 standard.

2. INTRODUCTION OF IEEE1451 STANDARD

2.1. The Goal of the IEEE1451 Standard

The goal of IEEE1451 is to develop a set of smart transducer interface standard by defining a set of common communication interface to solve the problem of compatibility between different networks, and realize the interoperability between different products of different manufacturers in the last.

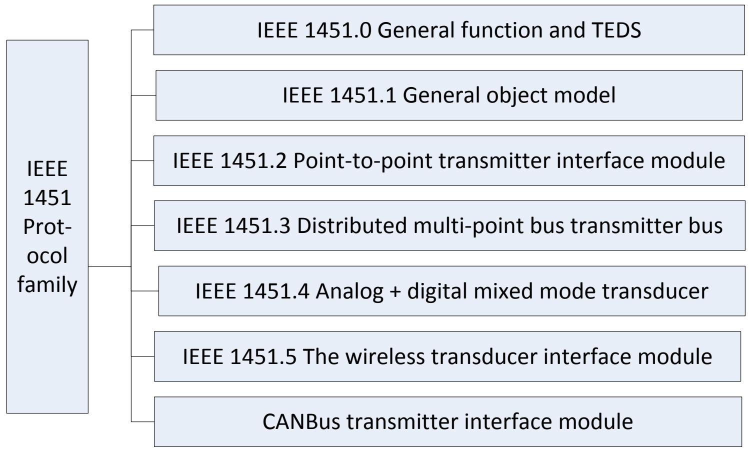

Fig. (1). The architecture of IEEE1451 protocol suite.

2.2. IEEE1451 Standard's Content

As a smart transducer interface standard suit, IEEE1451 describes a set of open, versatile, independent network communication interface for the transmitter which connect with microprocessor, instruments, measurement and control network system. The main content of these standards are about the definition of the transducer electronic data sheet named TEDS. TEDS is a memory area with special electronic format and it is always connected to the transmitter. TEDS stores the transmitter identification information, calibration information, modify data, and some information related to measurement, measuring range, etc. The goal of IEEE1451 is to acquire data in the transmitter regardless of the transmitter's being connected to the network through wired or wireless way.

So far, IEEE1451 standard protocol suite consists of seven standards, Its system structure and relationship are shown in Fig. (**1**) [3].

The content of these seven standards IEEE1451.0 to IEEE1451.6 is as followed [4, 5]:

IEEE1451.0: This layer includes general function, communication protocol, and electronic sheet (TEDS FORMATS). IEEE1451.0 provides a common simple protocol for different physical layers by defining the basic command set and the communication interface, so as to enhance interoperability between these standards.

IEEE1451.1: For various kinds of network technology nowadays, this standard defines the connection ways between smart transmitter to network, using object-oriented ideas to define a standard object model for networked smart transmitter, and define the software interface for each model class.

IEEE1451.2: IEEE1451.2 standard defines transducer interface module STIM, and details the hardware structure of STIM: puts forward the concept of TEDS, defines the transmitter TEDS and its data format, defines 10 digital interface independent lines named TII between the transmitter and the microprocessor hardware. It also defines the TII's stitch definition and communication protocols. TEDS on software makes it possible for different sensors to plug and play.

IEEE1451.3: This standard includes the definition of multipoint's distributed digital communication system and the format of TEDS. It is mainly used for acquiring synchronous data and communicating in the multipoint distributed smart sensor system.

IEEE1451.4: This standard contains the definition of mixed mode communication protocol and TEDS format. It mainly aims at the existing analog communication protocol in the transmitter. It supports the digital interface handle data on TEDS. On the other hand, it also supports the measurement of field instruments.

Sensors Plug&Play, based on the IEEE 1451.4 (TEDS) standard, brings plug-and-play capabilities to transducers. With plug-and-play technology, we can store a TEDS directly on a sensor. TEDS-compatible measurement systems can auto-detect and automatically configure these "smart sensors" for measurement, reducing setup time and eliminating transcription errors that commonly occur during sensor configuration.

IEEE1451.5: It establish a standard for wireless communication methods and data format for transducers. It will adopt necessary wireless interfaces and protocols to facilitate the use of existing wireless technology solutions and it will define a TEDS based on the IEEE1451 concept, and protocols to access TEDS and transducer data.

IEEE1451.6: It defines the TEDS and CAN bus interface.

3. SMART TRANSDUCER STRUCTURE

According to the contents of IEEE1451.0 - IEEE1451.2, IEEE1451 divides the smart transmitter into two parts, one part is smart transducer interface module, the other part is the network adapter which is also called network application processor. These two parts are connected to each other through 10 digital interface lines TII between them. The diagram of smart transducer block is shown in Fig. (**2**) [6].

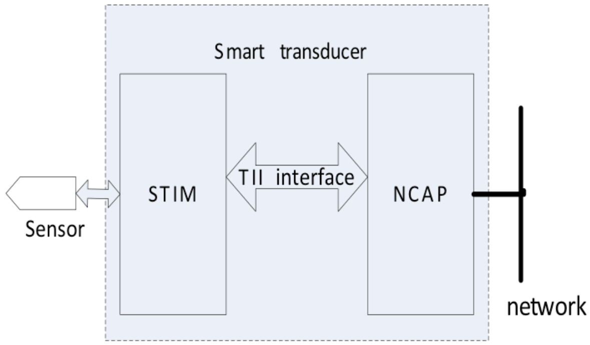

Fig. (2). Smart transducer structure.

Table 1. A virtual TEDS.

Field Description	Length (byte)
Manufacturers	2
Data format	2
Physical unit	2
Serial number	2
Measurement range	2
Correction coefficient	2
...	...

3.1. NACP Module

This module is responsible for network communication, STIM communication, data conversion, etc. The IEEE1451.1 standard defines its physical model. NCAP is the interface between transducer bus and the specialized network bus. We usually regard microprocessor as a core in hardware designs, it plays the role of the "brain" in the networked sensor [7].

3.2. STIM Module

According to the ways connected to NCAP, STIM can have a variety of different functions to suit for different application requirements. A STIM can support single or multiple different channels, it connects to the sensor at one end and connects to the actuator at the other end.

3.3. TEDS [8]

TEDS is embedded in STIM. It includes all the required information used to describe a STIM, such as manufacturers, data format, the physical unit, serial number, measurement range and the correction coefficient, etc. In the upgrading of the traditional sensor applications, the sensor information can be stored in TEDS. These data can be provided to NCAP or other parts of the system for STIM self-description and correction. The application of IEEE1451 standard simplifies the networked smart sensor greatly. A virtual TEDS is shown in Table **1**.

4. THE DESIGN OF A NETWORKED SMART AUDIO SENSOR BASED ON IEEE1451

There is not an unified field bus standard in the world. The existing Profibus, FF, Lonworks, HART, CAN and other standard bus protocol are incompatible. Different kinds of field bus products can neither interconnect or exchange nor unified configurate. That brings negative effects on the expansion and maintenance of the system. The sensor technology is mature nowadays and its application field is very broad. But, the kinds of smart sensors are limited, so the smart sensor scheme based on IEEE1451 standard solves this problem very well. Among IEEE1451 standards, the application of IEEE1451.2 is more widely.

This article designs a networked smart audio information processing system based on IEEE1451. The system adopts the “ARM +DSP” master-slave processors work design. It complete the interface design of networked smart sensor. WM8731 is used for gathering the audio information. Network signal processing mainly depend on the 32-bit ARM processor, that is to say NCAP design takes ARM as the core. STIM system adopts the DSP microprocessor as the core of design. The hardware include STIM and NCAP module design.

4.1. NCAP Module Design

The NCAP read data in STIM memory through TII interface and send the data to net after converting it to networked transmission format. Then clients can monitor sensors in real time through client software. After processed by CPU, these data will be sent to STIM module to control the smart sensor.

The CPU of NCAP module is a 32 bit microprocessor AT91RM9200 [9] of ARM kernel, The AT91RM9200 is a complete system-on-chip built around the ARM920T ARM Thumb processor.

Its features include:

Incorporates the ARM920T ARM Thumb Processor, 200 MIPS at 180 MHz, Memory Management Unit ,16-KByte Data Cache, 16-KByte Instruction Cache;

Low Power: 30.4mA on VDDCORE, 3.1mA in Standby Mode; Additional Embedded Memories: 16K Bytes of SRAM and 128K Bytes of ROM;

External Bus Interface (EBI): Supports SDRAM, Static Memory, Burst Flash, Glueless Connection to Compact Flash Smart Media and NAND Flash;

System Peripherals for Enhanced Performance: Enhanced Clock Generator and Power Management Controller, Two On-chip Oscillators with Two PLLs, Very Slow Clock Operating Mode and Software Power Optimization Capabilities, Four Programmable External Clock Signals, System Timer Including Periodic Interrupt, Watchdog and Second Counter, Real-time Clock with Alarm Interrupt, Debug Unit, Two-wire UART and Support for Debug Communication Channel, Advanced Interrupt Controller with 8-level Priority, Individually Maskable Vectored Interrupt Sources, Spurious Interrupt Protected, Seven External Interrupt Sources and One Fast Interrupt Source, Four 32-bit PIO Controllers with

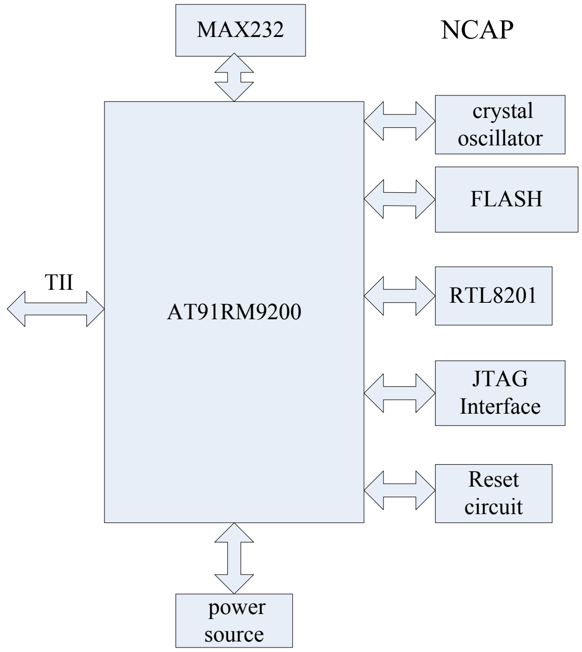

Fig. (3). NCAP principle block diagram.

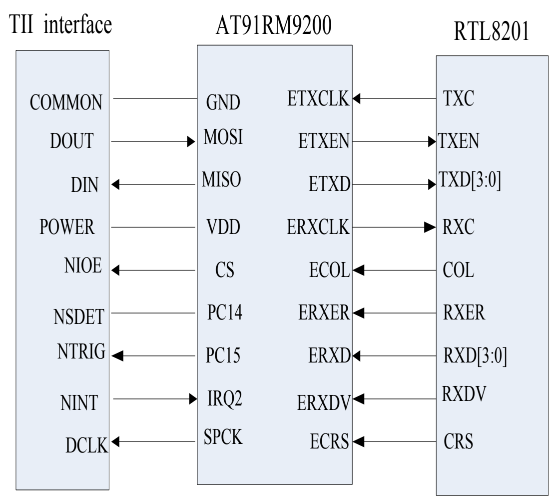

Fig. (4). The connection between microprocessor and network signal processor.

Up to 122 Programmable I/O Lines, Input Change Interrupt and Open-drain Capability on Each Line, 20-channel Peripheral Data Controller (PDC);

Ethernet MAC 10/100 Base-T: Media Independent Interface (MII) or Reduced Media Independent Interface (RMII), Integrated 28-byte FIFOs and Dedicated DMA Channels for Receive and Transmit;

USB 2.0 Full Speed (12Mbits per second) Host Double Port: Dual On-chip Transceivers (Single Port Only on 208-lead PQFP Package), Integrated FIFOs and Dedicated DMA Channels;

Multimedia Card Interface(MCI);

Three Synchronous Serial Controllers(SSC);

Master/Slave serial Peripheral Interface(SPI),etc.

We select SST39VF400A as FLASH, The space of SST39VF400A ois 256*16bit. MAX3110E is used for extension asynchronous serial port.

As for the Network signal processor, we adopted the Taiwan RTL company's RTL8201 to receive and send network signal. The RTL8201 is a single-chip/single-port 10/100Mbps Ethernet PHYceiver. It has a media independent interface(MII) and a reduced media independent interface(RMII). The RTL8201 implements all 10/100M Ethernet Physical-layer functions including the physical coding sublayer(PCS), physical medium attachment(PMA), etc. With on-chip DSP(digital signal processing) technology, the chip provide excellent performance under all operating conditions. NCAP principle block is shown in Fig. (**3**).

Fig. (**4**) shows the connection between microprocessor and the pin of network signal processor.

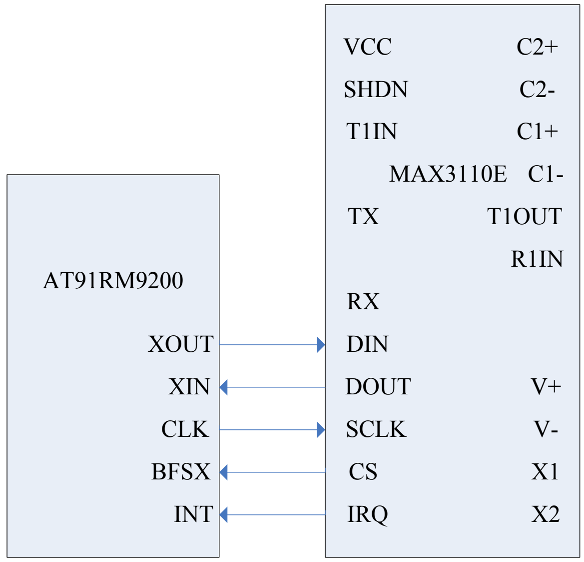

Fig. (5). The connection between AT91RM922 and MAX3110E.

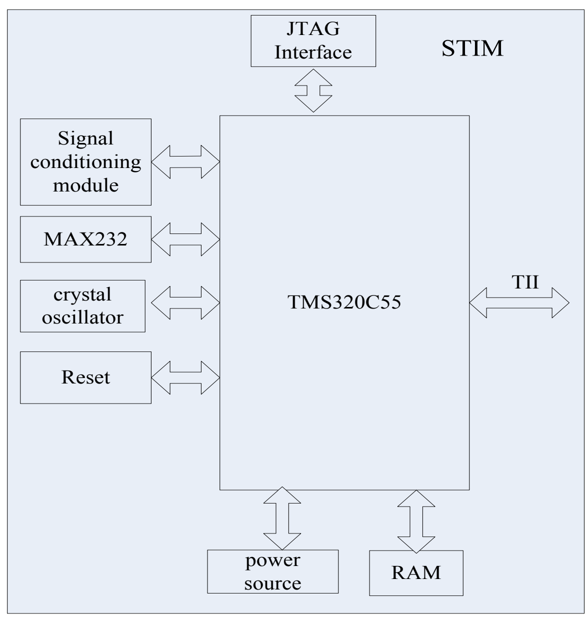

Fig. (6). STIM principle block diagram.

TII interface is composed of ten signals. Among the ten signals, DIN, DOUT, DCLK and NIOE realize the communication function., NTRIG and NACK implement the channel accessing, trigger and answer function about STIM. STIM send interrupt demand to NCAP through NINT signal. NCAP detect STIM through the NSDET signal to realize the plug&play of STIM. When TII executes writing operation, NCAP keep DCLK and send data to DIN. When TII executes reading operation, NCAP keep DCLK and get data from DOUT. When communicate, NIOE is a chip select signal, NACK is a trigger and answer signal.

TII interface driving program implements the initiation, open and close TII interface, write and read control, plug&play, etc.

NCAP can connect to PC through MAX3110E. When the NCAP debug, we need to connect the NCAP to PC. The programming, modification and loading of the TEDS need to be finished by PC. Configuring the sensor node on-line also need PC. The connection between AT91RM922 and MAX3110E is shown in Fig. (**5**).

4.2. STIM Design

4.2.1. STIM Principle Design

Sensor module (STIM) principle block diagram is shown in Fig. (**6**). It mainly includes: signal conditioning unit, serial communication unit, storage units, TEDS unit and TII inter-

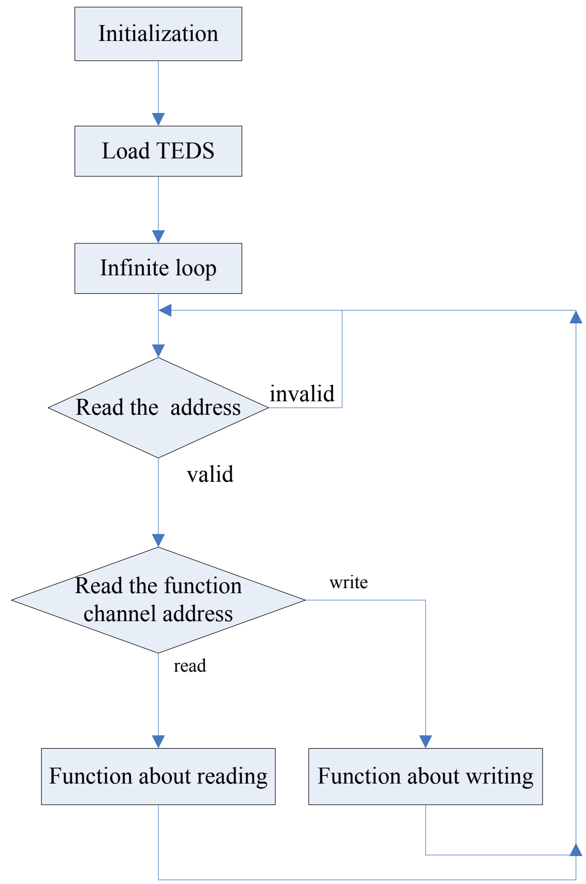

Fig. (7). STIM program flow chart.

face part. Its microprocessor is TMS320C55x [10]. The audio information source is a exploder.

TMS320C55x is a 16-bit fixed-point digital signal processor (DSP) which is specially designed by TI company for realizing low-power and high speed real time signal processing. Its price is low and it can perform stably. So it is suitable for telecommunication. TMS320C55x adapts enhanced Harvard structure, its speed is 100MIPS. It is composed of 8 buses and ten parts which include central processing unit (CPU), internal bus control, special function register, 64K random access memory (RAM), 64K read only memory (ROM), 64K I/O, serial port (SPI), parallel port, timer, interrupt system, etc. Its independent program bus and data bus allow it to access ROM and RAM in the same time, that means high-speed digital parallel operating.

TMS320C55x adopts Harvard structure in which program memory and data memory are divided. DSP can realize various digital signal process algorithms by special hardware multiplier. Its features are:

One multiplication together with one addition in an instruction cycle.

Independent program space and data space so as to access them in the same time.

On-chip high speed RAM, allowing to access to chips through data bus in the same time.

Almost zero overhead hardware support for loop and jump.

More than one hardware address creator.

Support pipelining.

4.2.2. STIM Software Design

The program flow chart of STIM is given as Fig. (**7**). It firstly initialize the system. It automatically loads TEDS data to on-chip memory. Then it will go to infinite loops. It will query addressing commands. If there come addressing commands, it will receive the channel address and function address. Otherwise, it will keep on waiting. Channel address determine which sensor channel is selected. Function address determine the function to be realized, including accessing sensor data, writing data, reading data, accessing TEDS data, etc. After executing the selected subprogram, it will return and go on with next loop.

The networked smart audio sensor system download TEDS through RS232 serial communication program which include PC program and the lower computer program.

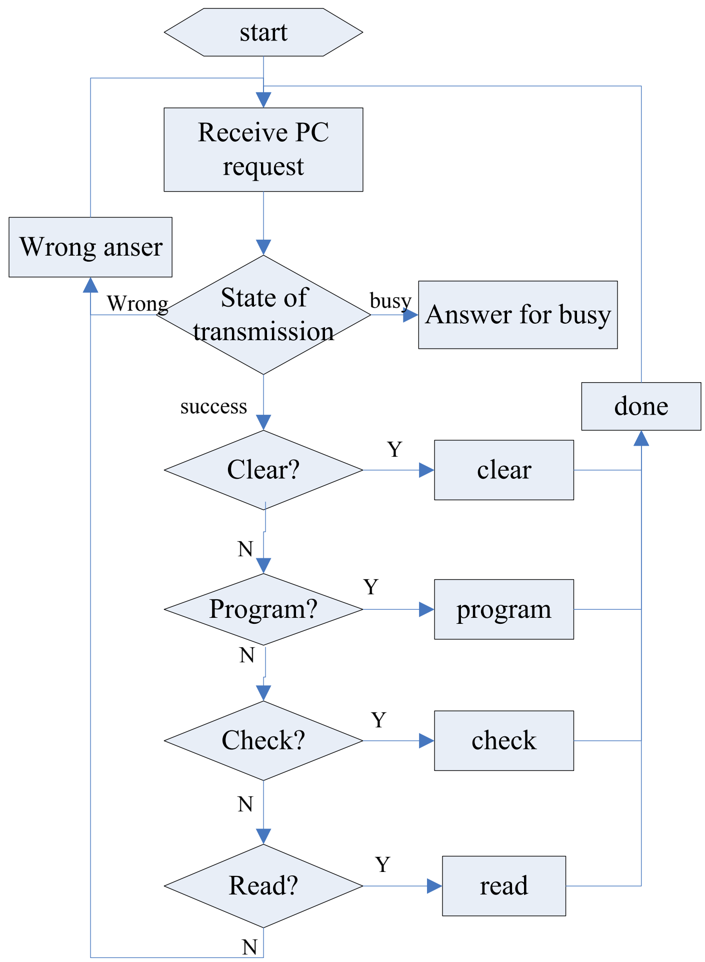

Fig. (8). The program flow chart of the lower computer.

The program flow chart of the lower computer program is as Fig. (**8**). The PC works in master way. The STIM works in slave way. The PC program will send request to the lower computer program. The lower program will return answer signal. After it communicates normally, the lower computer will implement the function according to the common from PC.

4.3. TII interface Design

TII interface is a digital interface between STIM and NCAP. It is defined a little complicatedly in IEEE1451. According to the demand of our project, we mainly considered the function about data transmission between STIM and NCAP. So we neglected those unnecessary signals, such as interrupt and trigger function signals NTRIG(trigger), NACK(trigger and transmission answer), NINT(interrupt) and NSDET(detection), etc. We reserved DIN(data input), DOUT(data output), DCLK(clock), NIOE(input/output enable), COMMON signals. The simplified TII interface is shown as Fig. (**9**).

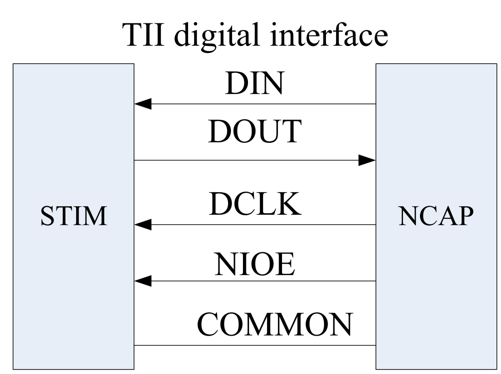

Fig. (9). The simplified TII interface.

CONCLUSION

Networked smart sensor based on IEEE1451 standard has become a development direction of sensor application. It has been applied in the author's networked smart explosion

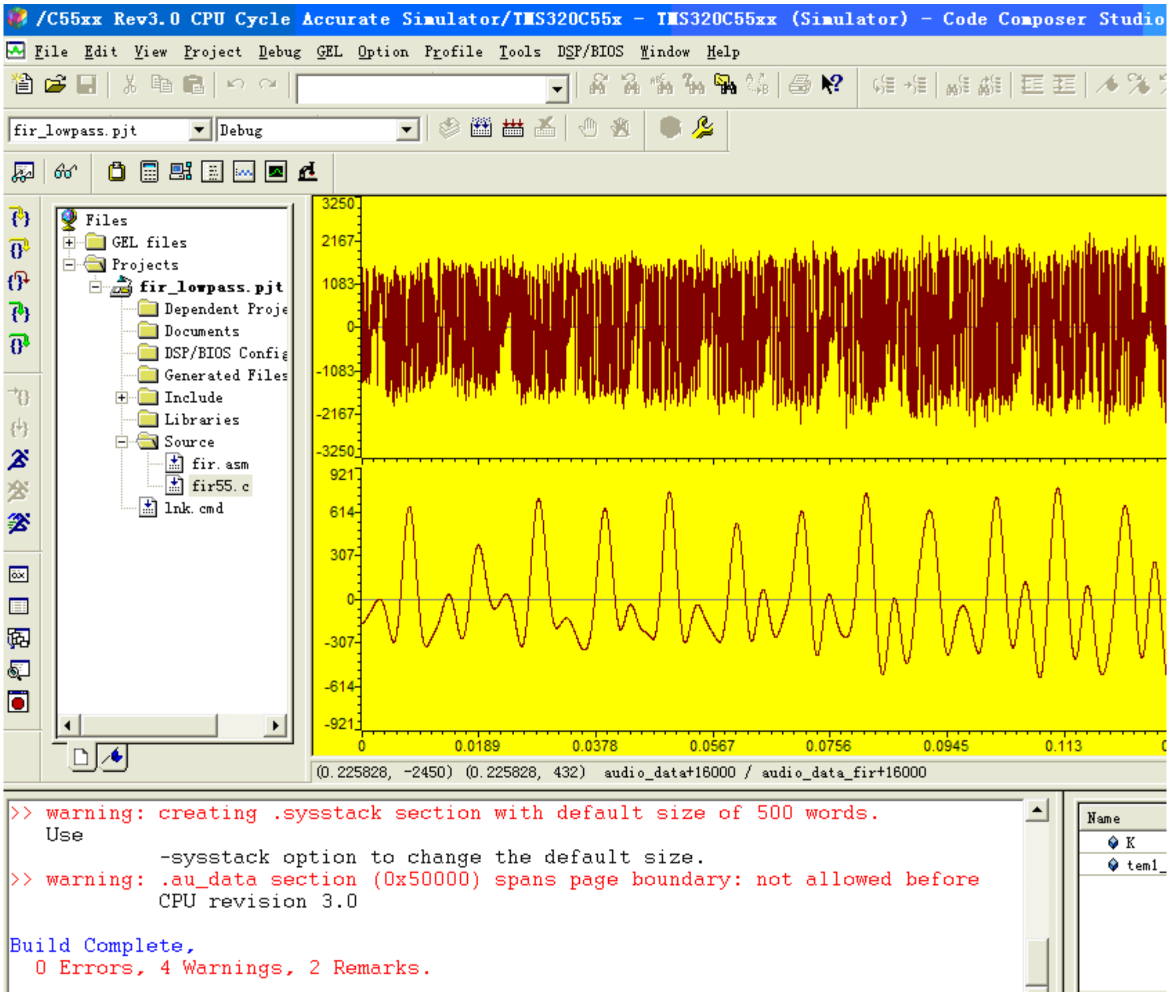

Fig. (10). Audio information waveform.

testing device, shaft angular displacement-measuring system and the sensor array nodes design project. It is fact that the application of IEEE1451 standard in networked smart sensor system can not only solves the problem of interface standardization, but also has good performance in improving the accuracy of measurement, sensor fault perception, judgment and decision-making, etc. In Fig. (**10**), the upper waveform is the original audio waveform. The under waveform is the audio waveform after software filter.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] Jeong-Do Kim, Jung-Hwan Lee. Sensor-Ball system based on IEEE 1451 for monitoring the condition of power transmission lines. Sensors and Actuators A ,154 (2009) :157–168

[2] Duan WenJie. Research and design of IEEE1451.2 smart transducer interface module,.Yanshan University, 2012.

[3] Zhang Shuai. Research on the networked and smart interface module for ocean observation. National Ocean Technology Center ,2013.

[4] J. Kamala, B. Umamaheswari. IEEE 1451.0 standard based smart readout for multi-rate control of system. Sensors and Actuators A ,154 (2009): 169-174.

[5] Li Zeming, Li Jinming, Yang Yanjiao. Implementation to Smartize Temperature Sensor Based on IEEE1451.2 Standard. Computer Measurement & Control, 2013.21(10):2891-2894.

[6] S.R. Rossi, E.D. Moreno.A VHDL-based protocol controller for NCAP processors. Computer Standards & Interfaces 31 (2009): 515-522.

[7] Chen Xiangqun, Guo Yishu. Research on IEEE1451 Smart Sensor Interface Standard.Chinese Journal of Scientific Instrument, volume 23, issue 5,2002:10.

[8] Yang Haiguang. Prototype Design and Implementation of Smart Sensor Network based on the IEEE1451 Standard. North University Of China.2013.

[9] Li Qike. Design of the Paper Quality Control System based on Industrial Ethernet. Chongqing University. 2013.

[10] Antonio Pardo. Gas Measurement Systems Based on IEEE1451.2 standard. Sensors and Actuators B ,116 (2006): 11–16.

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