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Utilizing UART Method for Realizing the TII of IEEE 1451

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Abstract: *In this paper, we used the programmable IC to accomplish a wireless Smart Transducer Interface Module (STIM), which is defined to the standard IEEE 1451.2 for using to transmit the acquired data. We also used Bluetooth technology to replace the Transducer Independent Interface (TII), and implement data transform between STIM and Network Capable Application Processor (NCAP), respectively. The STIM for defining by IEEE 1451.2 standard is implemented by the ALTERA MAX II CPLD. Final, two examples are experimented with this implemented STIM that is thermograph and step motor to prove this implemented equipments suit to IEEE 1451 standard. The most contributions of this paper are 1) accomplished IEEE 1451.2 by a Semi-customer technology, 2) provided a convenience data transform path via the STIM, 3) integrated the Bluetooth technology to IEEE 1451 system and to prove IEEE 1451.5, done this version with wireless.*

Keywords*: IEEE 1451, Semi-customer, Smart Transducer Interface Module (STIM), and Smart Sensor Node (SSN).*

1. INTRODUCTION

The technology of computer and communication are improved. Thus, both wire and wireless communication are used to transmit the requirement data among devices, in any case either homo- or hetero-devices. For instance the remote terminal control system, which is combination of the basic hetero-devices: sensors, processors (or microprocessor), target drivers, and transducers. It would contain several homo-devices, such as a processing-unit node, in where is made up of sensor and processor. Nowadays, a novel remote control system contains of the above described homo-devices, hetero-devices, or both hybrid.

In order to solve the complex physical link and format decode/encode between sensors and processor. Since 1993, a new and simple communication protocol of IEEE 1451 standard [4, 5] was issued. Consequential, the standards of IEEE 1451.X family were launched (shown in Figure 1) [11, 12]. The focuses of this standard was to offer a simplifying, easy, and useful remote measurement system between sensors and host-processor, or between host-processor and drivers. For sensor side, in which has a plug and play (PNP) feature.

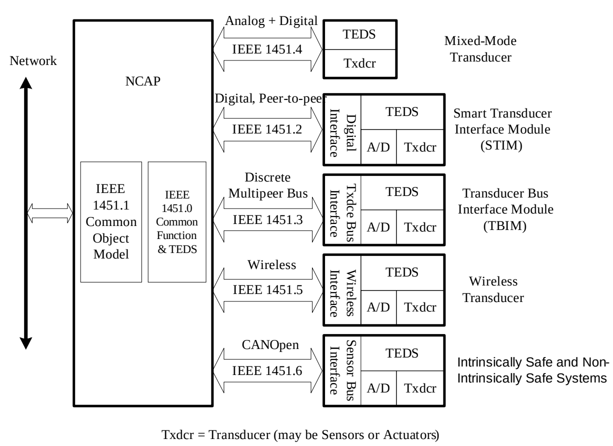

Figure 1: IEEE 1451.X Family [11, 12].

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In this paper, we followed the definition and protocol of IEEE 1451.2 [1, 2] to accomplish a Smart Transducer Interface Module (STIM) with UART (called UART-STIM) and NCAP. That is employing UART to realize the TII. The W-STIM was implemented on Altera MAX II Starter Kit [6] and the NCAP was achieved by C++ Builder 6.0 in PC, individually. We also demonstrated the data loss rate and accuracy while the measurement data was transmitted from sensor to PC via this W-STIM. In this paper, we will exploit the semi-consumer CPLD to implement a STIM. The advantages of this implemented STIM are small size, more easy development, higher speed, and lower cost.

The rest of this paper is organized as follows. Section 2 surveys the IEEE 1451.x standard and relation works. In section 3 describes the proposed STIM structure of smart sensor node. Section 4 illustrates the methodology for creating the proposed STIM. In Section 5 is representing the examination of the implemented smart sensor node. Finally, we remark the conclusion in Section 6.

2. THE STANDARD OF IEEE 1451.X

Since 1993, the concept of IEEE 1451 was first to issue, further the NIST (The National Institute of Standards and Technology) and IEEE (Institute of Electrical and Electronics Engineers) committee NI (National Instrument) in the Instrument and Measurement Forum discussed about the standard of smart sensors and its communication protocol in order to create a uniform/standard interface between instruments and other devices. The IEEE 1451 standard is comprised of four complete sub-standards. Each sub-standard may be used in a standalone fashion or as part of an overall IEEE 1451 family solution. To date, IEEE organization had balloted and accepted the IEEE 1451 standard from IEEE 1451.1 to IEEE 1451.6. The characteristics of them are brief described as follows:

IEEE 1451.1 defines a network-independent information model, enable transducer to interface to network capable application processors (NCAPs), in which the transducer and its components are defined by an object-oriented model. The components of model is combined to a set of specified attributes, actions, and behaviors, This standard optionally supported all of the interface model communication approaches taken by the rest of the IEEE 1451 family, such as STIM, TBIM, Mixed-model transducer. The interface of sensor and actuator is a independent hardware and mapped by a standard API.

IEEE 1451.2 defines a TEDS (Transducer Electronic DATA Sheet) and its data format, a standard digital interface and the communication protocols used between the transducers and the microprocessor. The 1451.2 standard offers 10-wire electronic signals, and read and write logic functions to access the TEDS and transducers. At all time, the TEDS is located with transducers and as a part of the STIM. The TEDS contains information to describe the transducers, which are embedded in the STIM. Thus the detail of TEDS is varied with each specific implemented STIM.

IEEE 1451.3 defines the specification for a standard physical interface for connecting multiple physical separated transducers in a multidrop configuration.

IEEE 1451.4 defines a specification that allows analog transducers to communicate digital information for the self-identification and configuration. It also allows the digital data to be shared with the analog signal from the transducers using a minimum set of wires. It is less than the 10-wire requirement of the IEEE 1451.2. In 2000, Conway *et. al.* used the ADuC812 micro-converter chip and HB Bfoot 66501 to implement STIM and NCAP, respectively. Then also apply to measurement the temperature via AD590 sensor.

The development of the standard IEEE 1451 intends to normalize and simplify the interconnection between transducer systems using networks, such as Ethernet or CAN. Moreover, a lot of interesting features are introduction of nodes in the network. For the wireless application of IEEE 1451, in 2001's, [2] had proposed a CrossNet architecture, in which was combination of several sensor pack nodes and data access ports. The data is transform between both using Bluetooth wirelesses. The plug-and play sensor includes sensor/actuator, microprocessor, and flash memory TEDS.

The IEEE 1451 family is a tip and smart standard for defining the sensor transducer. Thus it can be developed and manufactured by the System-on-Chip (SoC) Techniques. Such Castro *et. al.* [4] used FPGA, Virtex XCV800 from Xilinx, to accomplished a smart sensor to suit for the EMES (Micro Electro Mechanical System), in the future. In 2003's, [5] also used VHDL model, under PIC16C62, to implement STIM.

3. STIM STRUCTURE

We will develop a wireless STIM in the 1452.1 of the standard and has a UART interface. And defined the STIM is an element that deals with the transducers of the system. The control unit governs the transducer circuitry and interfaces to the outer devices through a standard connector using wireless techniques.

This proposed STIM is achieved according to the IEEE 1451.2 standard and integrated the Bluetooth wireless module to implement data transform each other. In the PC side has an USB interface to be made of the Bluetooth Dongle for the NCAP of PC that the structure of this issued STIM is shown in Figure 2 that is accomplished by a programmable semi-consumer IC, Altera MAX II CPLD EPM1270T144C5ES, and to be connected to a personal computer via the NCAP.

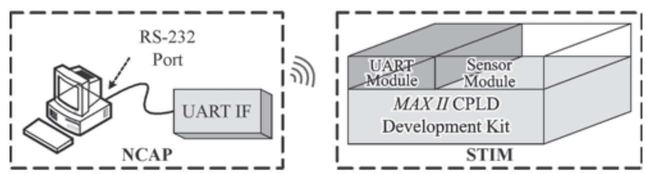

Figure 2: The Structure of UART-STIM.

3.1. UART-STIM Design

Figure 3, shows the detail architecture of proposed UART-STIM STIM, which is combination of frequency generator, controller, SPI transferor, UFP, UART, ADC control unit. This UART-STIM is accomplished by the MAX II CPLD devices. We also add some extra circuit into the Wireless STIM PCB, such as Bluetooth modules, sensors, regulator, and A/D Converter.

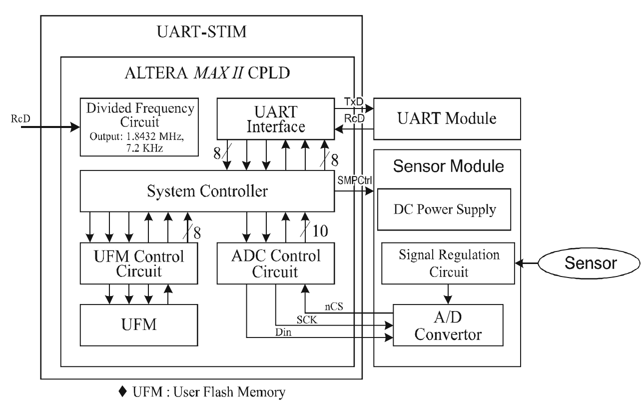

Figure 3: UART-STIM and Sensor Module

The relation of external sensor module and UART-STIM is shown in Figure 3. The W-STIM is accomplished in MAX II Starter Kit development board. Under the Start Kit, we used Very High Speed Integrated Circuit Hardware Description Language (VHDL) to implement the following units of W-STIM, such as frequency divider, UART module, UFM control circuit, ADC control circuit, controller, and User Flash Memory (UFM).

Otherwise, we also create an off-board sensor module, in which includes the power supply control circuit, sensor circuit, and A/D convertor.

3.2. Frequency Divider

For supporting different kinds of frequency to the UART module, controller, UFM, and A/D convertor (shown in Table 1), thus we program a frequency divided circuit in MAX II Starter Kit. In this MAX II CPLD has an 18.432MHz OSC source. The divisor is 10 and 2560, and obtaining the results is equal to 1.8432 MHz and 7.2 KHz, respectively. 1.8432 MHz is needed to UART module and controller, and 7.2 KHz supports to UFM control circuit and A/D control circuit.

Table 1
Module and Requirement Frequency

Source Frequency	*Module Name*	*Useful Frequency*
18.432 MHz	UART module	1.8432MHz
	Controller	1.8432MHz
	UFM control circuit	7.2KHz
	A/D control circuit	7.2KHz

3.3. RF Interface

In this paper, we exploit UART (RS-232) interface to realize the TII that is based on the below two reasons. First, for the UART interface has the advantages: cheap, simple, easy operation, and well-known in industry. Second, in the MAX II Starter Kit supports a ICL3232 which has the features of RS-232 requirement. So we can quickly and correctly realize the TII of STIM.

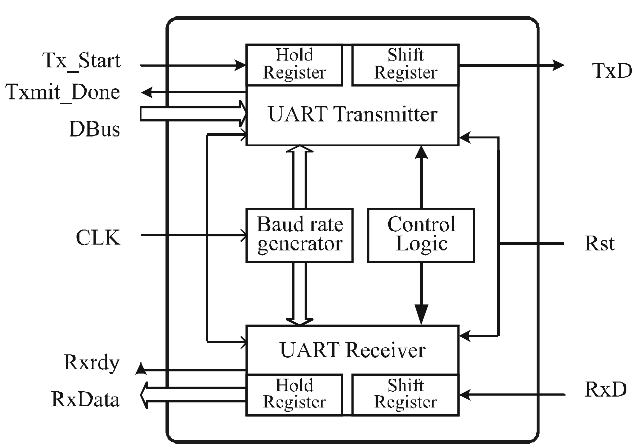

Figure 4: UART Block

For the UART module, it architecture is referred to QuickLogic Co. [10]. The detail structure of used UART module is shown in Figure 4. The UART interface is designed in the programmable CPLD to follow the basic concept of data transfer and handshaking protocol, which is shown in Figure 5.

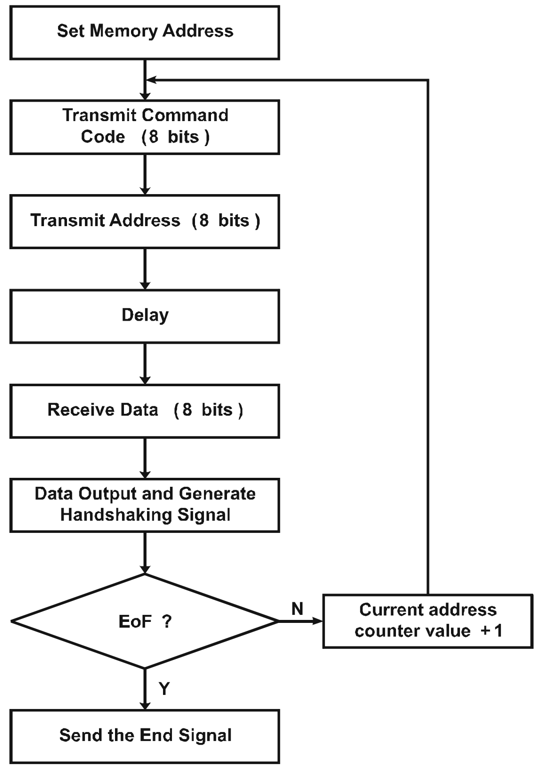

Figure 5: The Control Flow in UART.

3.4. Controller

This controller is the most important unit to be embedded in W-STIM and use to handle the other units of W-STIM, and the sensor module. The controller owns the all properties of a real STIM, and it is the core of STIM, too. All defined

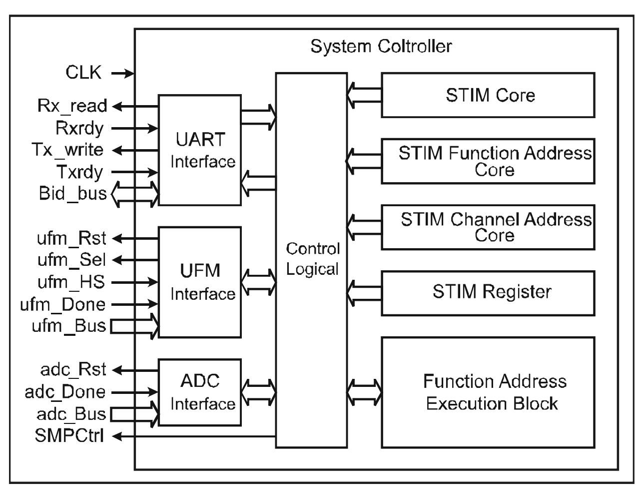

Figure 6: Block Diagram of Controller.

function address of IEEE 1451.5 is also controlled by this controller. The relation between controller and the other units of W-STIM is illustrated in Figure 6.

3.5. UFM

The UFM (User Flash Memory) is a Flash memory and has embedded in MAX II CPLD. We can through the VHDL, i.e. *MegaFunction* ( ), to program the various values of memory. Because the TEDS of IEEE 1451.2 must be stored in a un-volatility memory, so we use this UFM to achieve TEDS.

In this demonstration, not only use UFM to store the TEDS, but also program the connection interface as a serial port. The UFM is designed and the detail structure is shown in Figure 7, too.

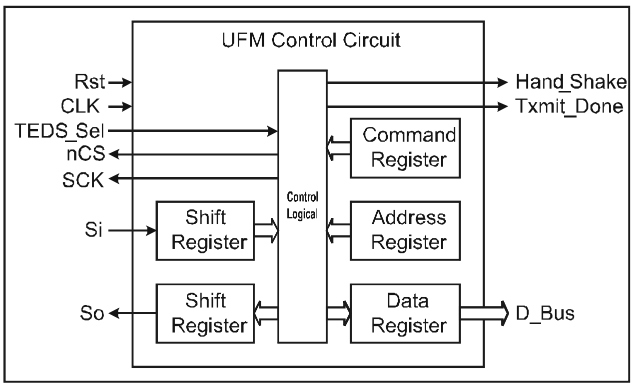

Figure 7: A Programmed UFM.

3.6. A/D Control Circuit

In order to verify our design is feasible, we made channel 1 to connect a thermo-sensor AD590. For the sensed temperature value is analogy type, thus it must transfer to digital type before reading from sensor module to CPLD chip. The reading process is controlled by the A/D control circuit, which structure is shown in Figure 8 and achieve in the MAX II CPLD,

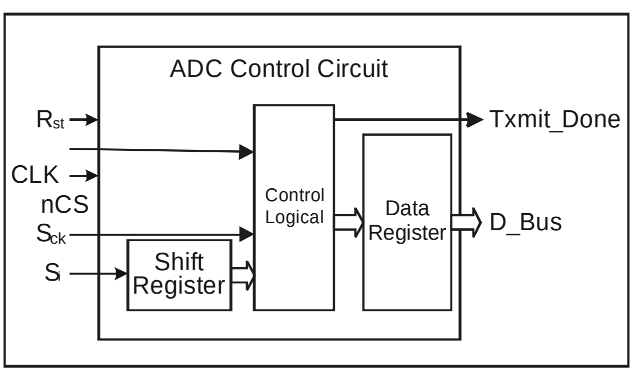

Figure 8: ADC Control Circuit.

For converting the analog to digital, the Microchip MCP3001 A/D converter is embedded in the sensor-module board. Through this MCP3001 chip, a set of digital data are sent to the STIM block with serial model via the SPI (Serial Peripheral Interface). For the signals conversion flow by ADC is shown in Figure 9.

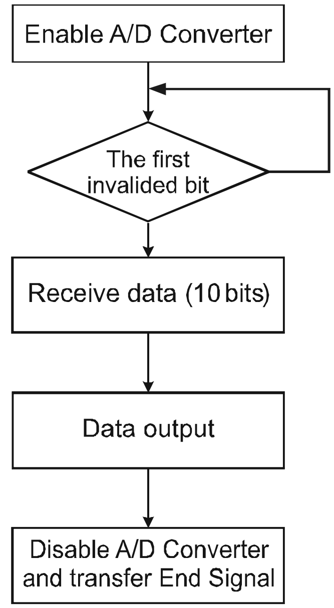

Figure 9: The Signal Conversion Flow of ADC.

3.7. Sensor Module

In order to verify our experiment, we design a sensor module to an external board and experiment on channel 1 (Ch. 1) of the UART-STIM. This sensor module will extend to a smart sensor node, in the future.

The sensor board is used to detect the temperature. It contains of a *Intersil* AD590 [8] thermo-sensor, A/D converter, and DC power supply regulator.

The detail controlled circuit [8] for AD590 is shown in Figure 10. As for the key features of AD590 are listed as follows:

1. linear current output is 1 μA/°K)
2. operation temperature range from -55 °C to 150 °C
3. individual input voltage and output current
4. operation work voltage is from 4 Volt to 30 Volt
5. lower interference
6. low cost

A/D convertor (ADC) is used to transform the input sensed analog signal into digital output signal. A Microchip MCP3001 ADC [9] with 10-bit is used and the control circuit is shown in Figure 11. The important features of Microchip MCP3001 ADC are:

1. 10-bit resolution
2. SPI
3. operation voltage ranger : 2.7 Volt to 5.5 Volt
4. the sample rate is 200 ksps at 5V, and 75 ksps at 2.7V
5. temperature range: from -40 °C to 85 °C

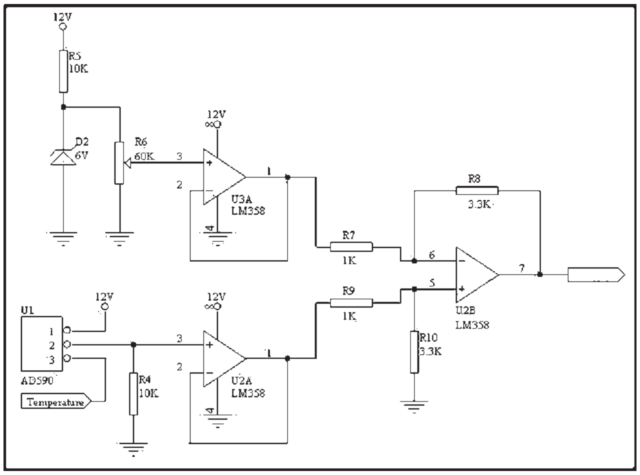

Figure 10: The Circuit of Sensor Node.

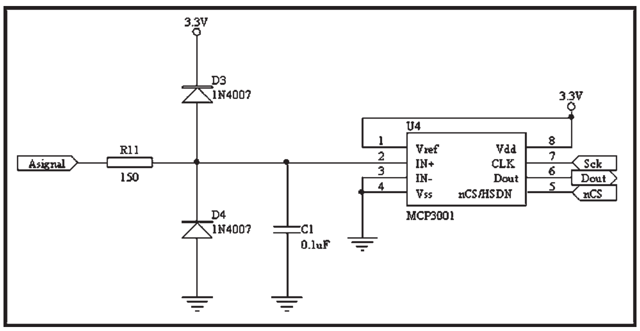

Figure 11: A/D Convertor Circuit.

IEEE 1451.2 can control individual channel through each command define to set/reset the controlled devices. Thus, we use a MOSFET to control the power supply ON/OFF. For the feature of MOSFET the same as switch and this power switch is directly controlled by the controller of STIM via Ch. 1. The detail circuit of power supply is shown Figure 12.

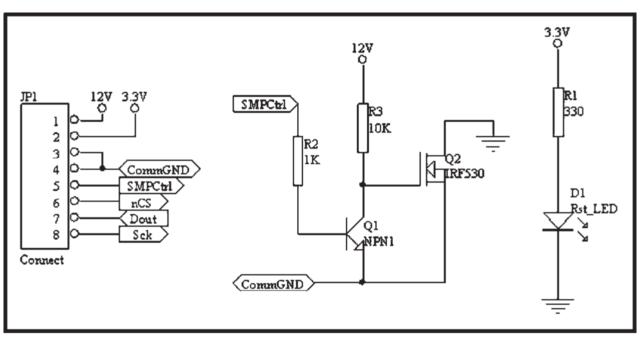

Figure 12: Power Supply Circuit.

40NCAP

The goal of NCAP is used to control and test the implemented UART-STIM and to confirm whether it all right in the PC side. This NCAP is implemented by C++ Builder 6.0 [7] in PC.

The design concept of this NCAP follows the design flow of Figure 13. In Figure 14, represents the implemented GUI model NCAP with traditional Chinese. It contains of several module, such as serial port selection and control, channel selection, control command, Meta-TEDS and Ch1-TEDA contents, IEEE 1451.2 register, and NCAP status, etc. them are brief described as follows:

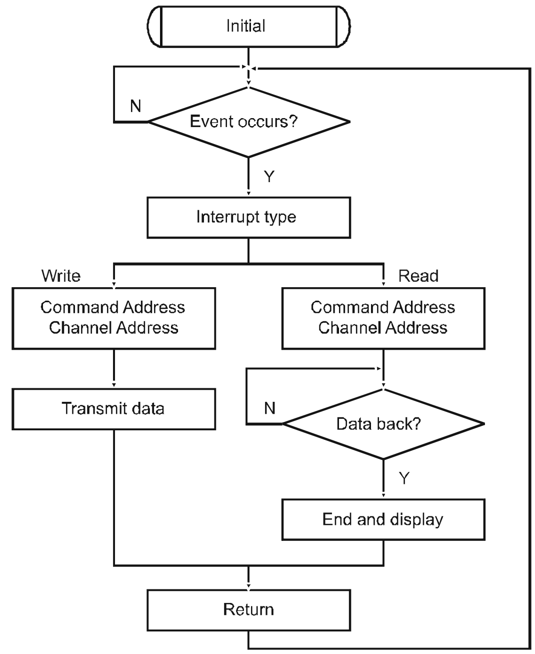

Figure 13: The Control Flow of NCAP

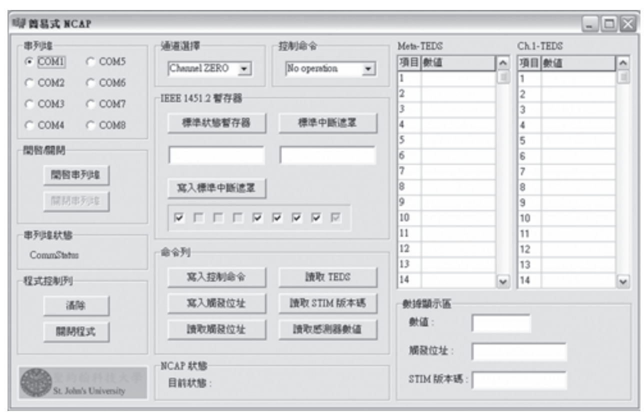

Figure 14: The GUI of NCAP in PC.

The fields of serial port selection and control module indicate the utilized COM port and port work status. The control command is used to set the following options: read TEDS, read STIM version, read sensing value, read/write the trigged address, and write the control commands.

For the IEEE 1451.2 register, has three parts such as state register, and interrupt register and interrupt mask register to indicate the current work status and interrupt request, individually.

The field of Meta-TEDS and Ch1-TEDA both indicate the values and trigging address information of it mapping.

The field of NCAP state will show the currently work status, such as read/write register, trigged address, or command.

5. EXPERIMENT

The real sensor module circuit and the MAXII CPLD are shown in Figure 15 and Figure 16, respectively. We implemented the UART-STIM in MAX II CPLD. Figure 17, represents the real world connection from UART-STIM to the simplified NCAP which is configured in the PC end and uses RS-232 interface to receive the measured data from UART-STIM terminal.

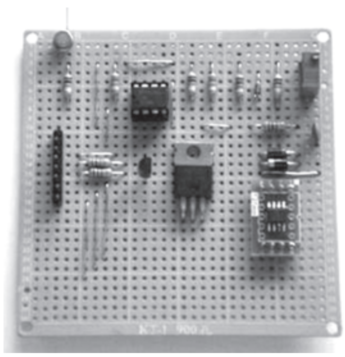

Figure 15: The Real Circuit of Sensor Module.

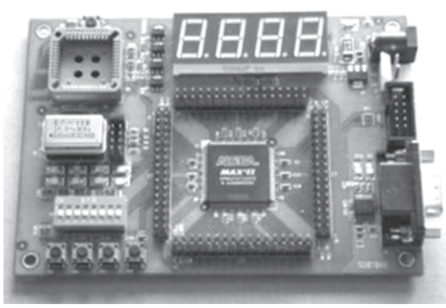

Figure 16: Realizing STIM in MAX II CPLD.

Figure 17: The Real Work between UART-STIM and NCAP.

To verify the accomplished STIM and simplified CAP are practicability. They are tested under a wire environment using UART protocol. Two test-items are processed that is data loss rate and accuracy of temperature by this UART-STIM. Both results are described as follows:

For the data loss rate, it is tested in the channel 1 TEDS and the length of useful data is 96 Bytes. This tested data is transmitted through UART interface repeating 250 times. The results are shown in Table 2, where we set a checkpoint while increases to 50 times and record the number of error bit. Obtaining Table 2, we find this implemented UART-STIM very steadily and high quality. The loss rate equals to 0, we speculate the reasons: one is transmitted by a steadily wire mode, the other is excised in an ideal environment where without noise. Though has the above reasons, those don't alleviate the contribution of the supposition this paper.

Table 2
Data Loss Rate of UART-STIM on 96 Bytes

Transmitted times	50	100	150	200	250
Error bits	0	0	0	0	0
loss ratio	0 %	0 %	0 %	0 %	0 %

For the measurement accuracy, we directly connect a temperature sensor, AD590, to UART-STIM. Furthermore, the sensed temperature value is transmitted to the NCAP in PC end via the UART interface. From the NCAP GUI, we can clearly obtain the measurement temperature. The comparison result of real temperature and measurement temperature are listed in Table 3. We find the error range from 0.1 ^oC to 0.5 ^oC. This error is due to the real temperature to be observed by a mercury column thermometer.

Table 3
The Accuracy of UART-STIM (Unit : ^oC)

Voltage value (V)	*Measurement Temperature (^oC)*			
	first measure	*second measure*	*third measure*	*Real temperature*
0.81	16.42	16.52	16.23	16.2
0.23	4.89	4.69	4.89	4.6
1.52	30.60	30.89	31.09	30.4
1.65	33.33	33.43	33.23	33
2.83	56.89	56.95	56.70	56.6
2.73	54.74	54.74	54.94	54.6
3.23	64.71	64.91	64.71	64.6
3.37	67.64	67.55	67.64	67.4
4.47	89.25	89.44	89.74	89.9
4.24	85.04	85.24	84.85	84.8

6. CONCLUSIONS

The main purpose of this paper is to accomplish a STIM and link to NCAP through UART methodology. We call those implemented equipments UART-STIM and Simplified NCAP, respectively. The STIM is evaluated by the MAX II Starter Kit, and the Simplified NCAP is implemented in PC end with C++ Builder 6.0, too.

The experiment results show our idle is feasibility and steadily works right while the data transmit between STIM and NCAP via RS-232.

In the future, we will integrate the sensor module and STIM into a chip to realize the system-on-chip. The IEEE 1451 standards had issued since 1993, still now had a few papers published. Thus, it has much room to develop there are:

1) Using other wireless technique to replace the presented Bluetooth.
2) Exploiting broadcast model with wireless for multiple-STIM.
3) Embedding the NCAP and STIM into one programmable chip, such as CPLD or FPGA.
4) Using full-custom technology to implement the smart sensor node (SSN) to a SoC.
5) Extending the concepts of network and SSNs to a Smart Sensor Network Node (SSNN) to establish flexible smart networks.

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