An FPGA Based Real-time Remote Temperature Measurement System

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***Abstract*— This paper presents a wireless re-programmable real time temperature measurement system designed using the hardware description language and realized in hardware using the field programmable array (FPGA). The proposed system is able to measure the real time temperature of various remote locations with each of them to an accuracy of 0.25 °C. It uses wireless transmission with the data rate of 115Kbytes/s, to transmit the measured temperatures to the central control system for motioning purpose. In addition, the proposed system incorporates feature that controls the temperature at the remote locations in real time. This system effectively works for a distance of 60m between the temperature measurement locations and the control station. Since this proposed system uses a re-programmable controller, it is possible to customize the design to various industry applications. This paper presents the simulation and experimental results of the proposed system.**

***Keywords*—FPGA; real time temperature measurement; wireless temperature measurement.**

I. INTRODUCTION

Many hostile industries, warehouse, containers and other facilities use the temperature measurement system usually to monitor the temperature. All such industries essentially require a system that measures the temperature accurately and then effectively transmit the measured temperature to the control room to monitor and control the temperature. Such a system should be efficient enough to improve energy efficiency and quality [1].

Researchers have developed many efficient temperature measurement systems. One such a real time temperature measurement system for semiconductor devices presented in [2] uses a microcontroller and parallel wire communication for the data transmission. The work presented in [3] uses an opto-electronic instrument for measuring the temperature. A microcontroller based temperature measurement and control system using serial wire communication is presented in [4]. A temperature measurement and control system using FPGA and wired serial communication for the data transmission is presented in [5]. A wireless RFID based temperature measurement system is presented in [6].

While this paper presents a system design that is capable of measuring real time temperature at various locations to the accuracy of 0.25 °C and unlike conventional method of transmitting the measured temperature over the wires, this proposed system transmits the temperature wirelessly to the control station. Thus, significant work involved in routing the long wires and hence the delay in the transmission possibly be avoided. A common controller in the remote location receives measured temperatures for monitoring the temperature. It also broadcasts the necessary control signal to the appropriate temperature measurement station (TMS). Each of the TMS has the proposed system that has been designed using the Very High Speed Integrated Circuit Hardware Description Language (VHDL) and implemented on an FPGA. The figure 1 shows the block diagram of the proposed system.

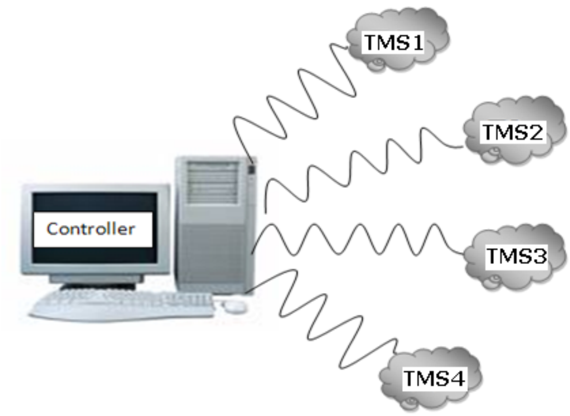

Figure1. Block diagram of the proposed system

II. ARCHITECTURE FOR WIRELESS TEMPERATURE MEASUREMENT SYSTEM

The Figure 2 shows the proposed architecture of a TMS. In each TMS, a K type thermocouple converts the temperature of the system into corresponding analog voltage. Then an analog to digital (A/D) converter MAX6675 converts the analog date to the digital data. In addition, this converter resolves temperature to 0.25°C and reads the temperature as high as +1024°C. The controller output is in the Serial Peripheral Interface (SPI) read only format. An SPI controller on the FPGA reads the digital data from the controller serially and stores on the memory on the FPGA for the data manipulation. After the data manipulation, the data is send to the

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Bluetooth transmitter using the RS232 controller. Finally, the Bluetooth transmitter sends the temperature information to the remote controller wirelessly. A Graphical User Interface (GUI) developed in the central controller reads the data from various TMSs and represents the temperature graphically. In addition, the control signal from the GUI is send to various TMSs to control the heater temperature wirelessly. The entire system that is designed in VHDL and implemented on an FPGA and it is explained in the following session.

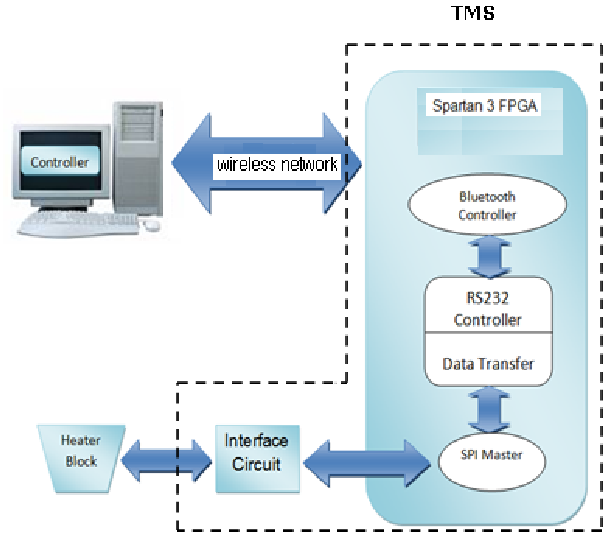

Figure 2. System Architecture

III. VHDL DESING FOR THE SYSTEM

The Register Transfer Level (RTL) view of the temperature measurement system is shown in Figure 3. It essentially consists of five blocks and they are SPI_MASTER block, data transfer block, TXD and RXD block, Bluetooth controller block and display block. The SPI block that works as a SPI master controller receives the temperature data from SPI slave, the MAX6675 chip, by initiating and synchronizing the serial transfer with the slaves using Chip Select (CS) and Serial Clock (SCK) signals [9]. The frequency of SCK is kept at 3.125 MHz and that is derived from the 50MHz clock and that is less than the maximum frequency (4.3 MHz) to which the slave device supports. In order to read the data from the slave, first CS must be held high for 220ms that is the conversion period for the slave and then CS must be held low for 16 SCK clock cycles, during this period the data is read in the SPI master. In addition, the SPI master has been designed to measure the temperature for every 500ms.

While the received temperature data has 16 bits, only 12 bits (14 to 3) of the data contain the temperature information and that is directly displayed using display controller on seven segments displays.

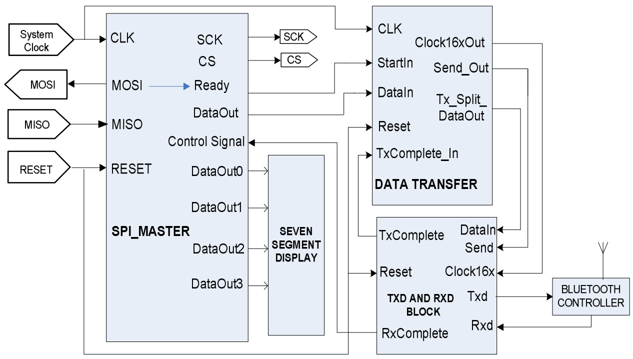

Figure 3 RTL View of the temperature controller

On the other hand the 12bit data is split in to two 8 bits in the data transfer block by concatenating with four dummy bits. This ensures that each data to be transmitted by the RS232 controller has eight bits data width. The transmitter block TXD of the RS232 controller is operating at 115 kHz, which transmits the data serially to the Bluetooth controller block, from where the data is transmitted to the controller wirelessly. At the control station, the data is received by the Blue tooth receiver and it feeds the data to a GUI which is developed in such a way to receive the data from the various TMSs and uses it to plot necessary graphs required for monitoring the temperatures.

In the reverse, the power supply to heater block that is situated in each of TMSs is turned on and off from the GUI wirelessly. The corresponding control signal with eight bit data width is send wirelessly using the Bluetooth transmitter in the control station. This is then received by the Bluetooth controller block of the respective TMS. The RXD of the RS232 controller receives the eight bit control signal from the Bluetooth receiver at the frequency 115 kHz. Then the control signal is send to the data control block which analyses the eight bit data, if all the bits are high then an output of the data block triggers a signal high, which in turn triggers the solid state relay that turns off the power to the heater. The power state of the heater remains as such until it receives the power on signal from the remote controller. To obtain a high data sampling rate the sampling clock of the TXD and RXD block is sampled 16 times the baud rate (Clock16x) which would be 1,843,200 Hz. In the following session discusses the simulation results of the VHDL model.

IV. SIMULATION RESULTS

The VHDL design for the temperature measurement system is simulated using the Modelsim tool. The figures 4a, 4b and 4c show the simulated results of SPI controller, Data transfer block and RS232 controller (Txd and Rxd Block) respectively. As shown in the figure 4a, the SPI master initiates the chip select CS and the clock SCK. The period of the SCK is 320ns and that translates to a frequency of 3.125 MHz. When CS is at low, the 16 bit data (1001011111110110_2) from the A/D converter is received serially in to the SPI master through MISO pin on the every rising edges of the SCK. As shown in the figure 4b, the datain of the data transfer block receives the 16 bit data (1001011111110110_2) from which the 12-bits temperature data (001011111110_2) is retrieved and concatenated with four bits (0000_2). Therefore the output of the data transfer block Tx_split_dataout has two eight bits of data 11111110_2 and 00000010_2. These two data are transmitted sequentially to the TXD and RXD block along with the control signal Send_out

Thus, the temperature information is transmitted to the remote controller. The following session discusses the experimental results.

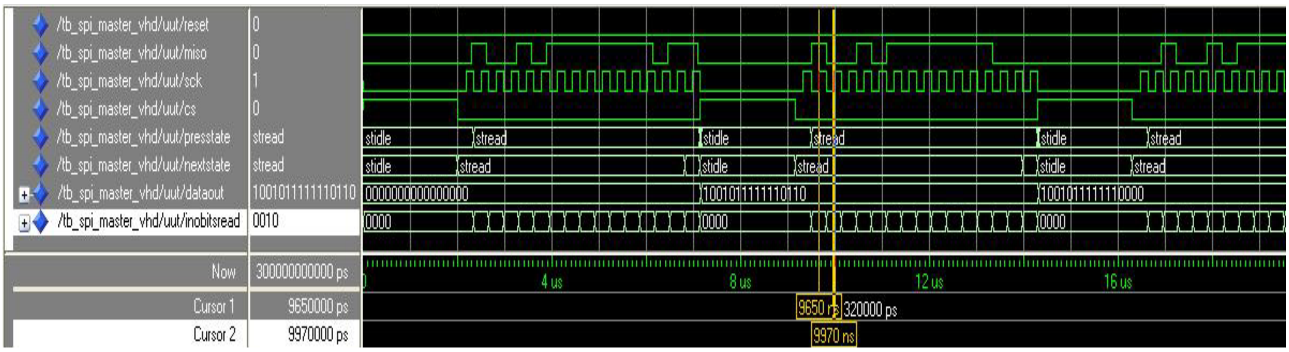

Figure 4a. Simulation of SPI Controller

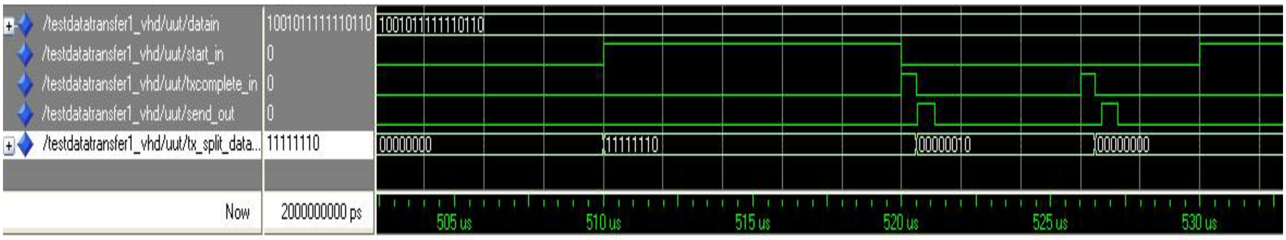

Figure 4b. Simulation of Data Controller Block

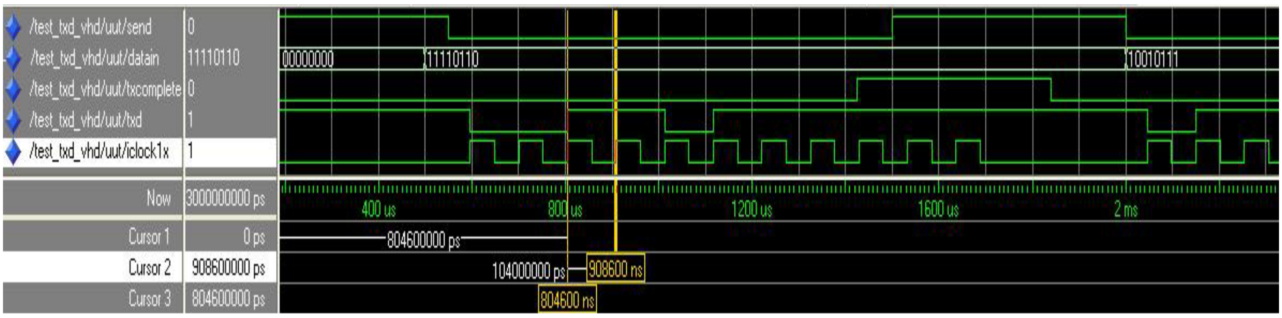

Figure 4c. Simulation of TXD & RXD (RS232) block

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The figure 4c shows that these data are transmitted serially to the Bluetooth block at a frequency of 115 kHz. After every successful transmission of the eight bits of data, Txd and Rxd block handshakes with Data Transfer block by sending a high pulse on Txcomplete. Then the next eight bits of data will be transmitted to the Txd and Rxd block. Actually the Send_out is toggled when either Startin or Txcomplete signals are toggled.

V. EXPERIMENTAL RESULTS

The VHDL design of the Real-time Remote Temperature Measurement System is implemented in the Xilinx Spartan3 FPGA and its I/O ports are connected to necessary peripherals. The experimental results from the proposed system are obtained on the GUI running on a computer at the control station. In addition, the temperature is measured using a commercial digital temperature measuring device.

Figure 5 shows the graphical illustration of the temperature measured by the GUI vs Temperature measured by the digital meter. The graph obtained shows a linear relation with an almost unity slope. Thus the result obtained proves that the temperature measured using the GUI is in close agreement with the temperature measured using commercially available digital device.

In another part of the experiment, three TMSs are located at a distance 20m, 40m and 60m away from the remote control station. In each TMS a commercially available digital temperature measuring device measures the temperature of the heater directly from the K type thermocouple output. The temperatures measured at each of the TMSs by using both commercial device and remote controller station show a very close agreement.

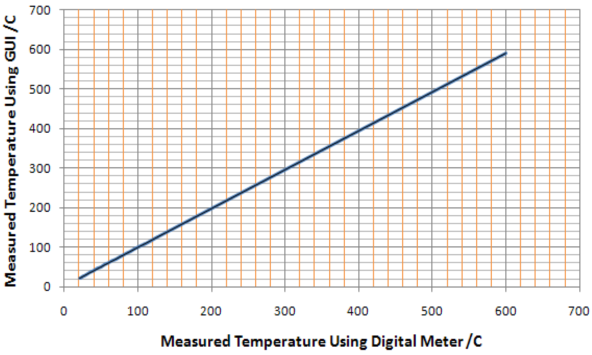

Figure 5. Experimental Result

VI. CONCLUSION

Thus, this paper describes a wireless temperature measurement system that is capable of measuring temperature at a distance 60m away from the control station and with an accuracy of 0.25°C. More over temperatures are measured in the interval of 500ms. Since the temperature controller was designed using VHDL which has been implemented in FPGA gives flexibility to further enhance the design and realize it in hardware rapidly. Thus it is believed that this system is suitable for hostile industries. Although many temperature measurement systems are commercially available, the project mentioned in this paper provides an alternative cost effective solution.

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