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Design and Implementation of I2C Protocol for Reading ADT7420 Sensor on Nexys A7 Board

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***Abstract*—This paper presents a detailed Verilog HDL implementation of an I2C protocol in particular designed to interface with the ADT7420 temperature sensor on the Nexys A7 board, offering temperature readings in both Celsius and Fahrenheit scales. By addressing intricate configuration challenges, we meticulously outline our FPGA-based solution, prioritizing efficiency and reliability in data transmission. Through comprehensive experimentation, we substantiate the accuracy and versatility of our design, showcasing its potential across diverse domains such as IoT, industrial automation, and environmental monitoring. This contribution significantly propels advancements in embedded systems development, offering a robust framework for temperature sensing applications.**

Index Terms: I2C Protocol, ADT7420 Temperature Sensor, Nexys A7 Board, Celsius and Fahrenheit Readings, FPGA Implementation, Verilog HDL, Embedded Systems.

I. INTRODUCTION

The Inter-Integrated Circuit (I2C) protocol, conceived by Philips Semiconductor (now NXP Semiconductors), is a versatile and efficient serial communication protocol widely used for intra-system communication among integrated circuits. The I2C protocol employs a simple two-wire interface comprising a Serial Data Line (SDA) and a Serial Clock Line (SCL) as shown in fig.1 . This dual-line configuration allows for seamless data exchange between multiple master and slave devices, making it an ideal choice for a variety of embedded systems applications.

I2C's appeal lies in its simplicity and scalability, facilitating communication with minimal wiring and straightforward implementation. In an I2C network, the master device initiates communication and controls the clock signal, while slave devices respond to the master's requests based on unique addresses assigned to each device. This protocol's efficiency and low overhead make it suitable for connecting sensors, displays, memory modules, and other peripherals to microcontrollers and digital systems.

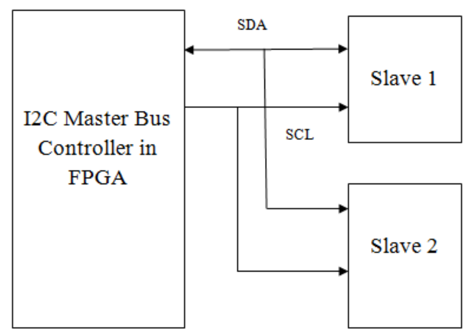

Fig. 1 I2C Master Slave

One well-known application of the I2C protocol is in temperature sensing, particularly using the ADT7420 digital temperature sensor. The ADT7420 is renowned for its high precision, offering an accuracy of ±0.25°C and supporting up to 16-bit resolution. This sensor operates over a broad temperature range, providing reliable and precise temperature readings, which can be presented in both Celsius and Fahrenheit.

This project aims to design and implement an I2C interface on the Nexys A7 FPGA board to facilitate communication with the ADT7420 temperature sensor. The Nexys A7 board, powered by the Xilinx Artix-7 FPGA, provides a robust platform for developing and testing digital systems. In this setup, the FPGA acts as the master device, orchestrating the communication with the ADT7420 sensor, which functions as the slave device.

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The core objective is to develop an I2C master module in Verilog, capable of configuring the ADT7420 sensor, reading temperature data, and displaying the results on the Nexys A7's seven-segment display. This system will not only read and display temperature values in Celsius but also convert and present these values in Fahrenheit, showcasing the practical application of the I2C protocol in real-time temperature monitoring.

The implementation involves several key steps: generating a suitable clock signal for I2C communication, managing the data exchange between the FPGA and the sensor, converting analog temperature readings to digital format using the ADT7420's built-in ADC, and finally, displaying the processed data on the FPGA's output interfaces. The project also addresses the integration of pull-up resistors necessary for proper I2C bus operation, ensuring reliable communication.

By integrating the ADT7420 temperature sensor with the Nexys A7 FPGA board via the I2C protocol, this project demonstrates the practical use of FPGA technology in embedded systems. It highlights the effectiveness of the I2C protocol in achieving precise temperature measurements and its utility in various applications requiring reliable sensor data acquisition and display.

II. LITERATURE REVIEW

Field-Programmable Gate Arrays (FPGAs) have emerged as versatile platforms for implementing various digital systems due to their reconfigurability, parallel processing capabilities, and high performance [1]. FPGA-based designs offer flexibility and scalability, making them suitable for a wide range of applications, including temperature monitoring systems [2].

The Nexys A7 FPGA development board, manufactured by Digilent, provides a convenient platform for prototyping FPGA-based designs and integrating sensor interfaces like I2C [3]. Equipped with components such as the ADT7420 temperature sensor, the Nexys A7 board facilitates the development of sensor-based systems for temperature monitoring applications.

Implementing I2C master controllers on FPGAs involves creating state machines to manage the communication protocol effectively [4]. Xilinx offers comprehensive guidance on designing these controllers, emphasizing precise timing and state transitions for reliable data transfer [5].

The I2C protocol, defined by NXP Semiconductors, enables simple and efficient communication between microcontrollers and peripheral devices like temperature sensors [6]. Utilizing just two wires (SDA and SCL) for communication, the I2C protocol is suitable for low-speed, short-distance applications [7].

The ADT7420 temperature sensor, developed by Analog Devices, is a high-precision sensor commonly used in temperature monitoring applications [8]. With a 16-bit resolution and compatibility with FPGA-based systems like the Nexys A7 board, the ADT7420 provides accurate temperature readings over the I2C interface.

Overall, the integration of the ADT7420 temperature sensor with the Nexys A7 FPGA development board demonstrates the effectiveness of FPGA technology in temperature monitoring applications. By leveraging FPGA's versatility and the simplicity of the I2C protocol, precise temperature monitoring solutions can be developed for various industries and applications.

III. PROPOSED SYSTEM

The proposed system aims to design and implement a reliable and efficient I2C communication interface on the Nexys A7 FPGA board to interact with the ADT7420 temperature sensor. This system will enable the FPGA to act as the I2C master, facilitating the configuration, reading, and display of temperature data from the sensor. The primary goal is to ensure accurate temperature readings and their presentation in both Celsius and Kelvin.

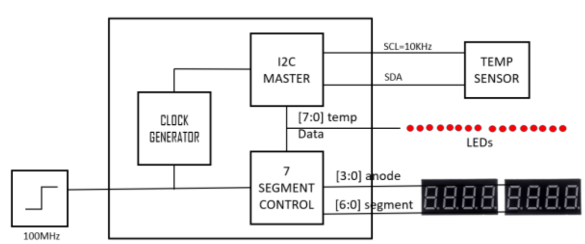

Fig. 2 Block Diagram

The system architecture comprises three main components: a Clock Generator, an I2C Master Module, and a Seven-Segment Display Controller. The Clock Generator converts the FPGA's 100 MHz input clock to a frequency appropriate for I2C communication, typically 200 kHz. The I2C Master Module manages the I2C communication protocol, including

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generating start and stop conditions, addressing the slave device, reading from and writing to the sensor, and controlling the SDA and SCL lines. Finally, the Seven-Segment Display Controller converts the digital temperature data into a format suitable for display on the FPGA's seven-segment display.

IV. METHODOLOGY

The state transition diagram shows the series of states involved in the I2C communication protocol for reading the ADT7420 temperature sensor. The I2C bus is waiting for a start condition when the system is initially in an idle state (S0). When the master pulls the SDA line low while the SCL line is high, it creates a start condition (S1), which initiates communication. Subsequently, the master transmits the ADT7420 sensor's 7-bit address, with the read/write bit set to '1' for a read operation (S2-S9). Over eight clock cycles, the address and R/W bit are transmitted.

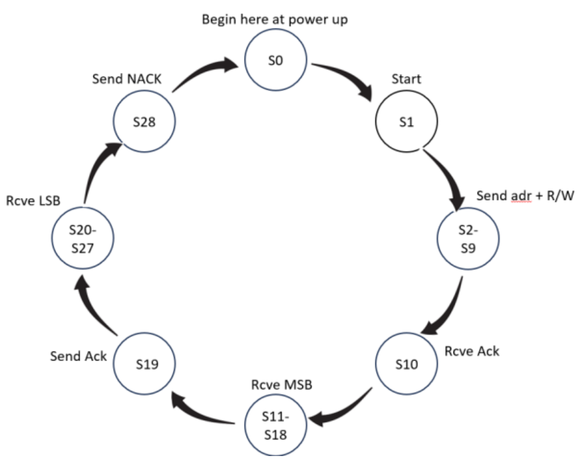
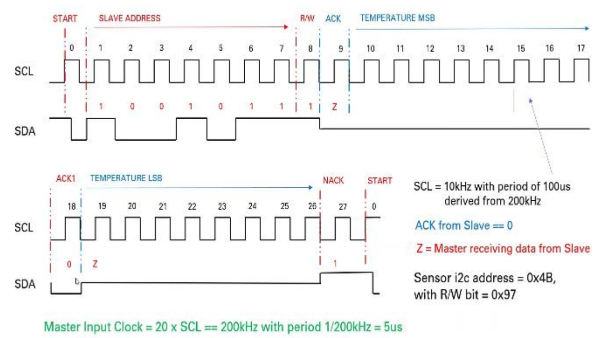


Fig. 3 State Diagram

Once the address is sent, the slave acknowledges receipt by pulling the SDA line low, which the master captures as an acknowledgment (S10). Following this, the master receives the most significant byte (MSB) of the temperature data from the slave over the next 8 clock cycles (S11-S18). After receiving the MSB, the master sends an acknowledgment (S19) to the slave to indicate successful reception. The master then receives the least significant byte (LSB) of the temperature data, again over 8 clock cycles (S20-S27).

In order to discontinue communication, the master releases the SDA line to high while the SCL is high, creating a stop condition and sending a negative acknowledgment (NACK) to signal the end of data reception (S28). In order to provide efficient temperature monitoring, these states guarantee that the FPGA, functioning as the I2C master, can precisely and consistently retrieve temperature data from the ADT7420 sensor.

Fig 4 Timing diagram



The timing diagram in fig 4 complements the state diagram by providing a detailed view of the signal transitions on the SDA and SCL lines during the I2C communication. The diagram starts with the I2C master generating a start condition, where the SDA line is pulled low while the SCL line remains high. The master then transmits the 7-bit address of the ADT7420 (0x4B) along with the read/write bit (R/W = 1) over the SDA line, synchronized with clock pulses on the SCL line. After the address is sent, the ADT7420 acknowledges by pulling the SDA line low during the ninth clock cycle. Following the acknowledgment, the master reads the MSB of the temperature data from the SDA line during the next eight clock cycles. After receiving the MSB, the master sends an acknowledgment by pulling the SDA line low during the 18th clock cycle. The master then reads the LSB of the temperature data during the subsequent eight clock cycles. When the master receives the LSB, it stops the read operation by sending a NACK (keeping the SDA line high) during the 27th clock cycle. The master releases the SDA line to high while the SCL line is high, creating a stop condition when the communication comes to an end. As seen in Table 1, the MSB and LSB of the temperature data are stored in register addresses 0x00 and 0x01, respectively.

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Table. 1 Temperature data address

Register Address	Description	Power-On Default
0x00	Temperature value most significant byte	0x00
0x01	Temperature value least significant byte	0x00

Temperature conversion formula

16-Bit Temperature Data Format

Positive Temperature = *ADC Code* (dec)/128

Negative Temperature = (*ADC Code* (dec) – 65,536)/128

where *ADC Code* uses all 16 bits of the data byte, including the sign bit.

Negative Temperature = (*ADC Code* (dec) – 32,768)/128

where Bit 15 (sign bit) is removed from the ADC code.

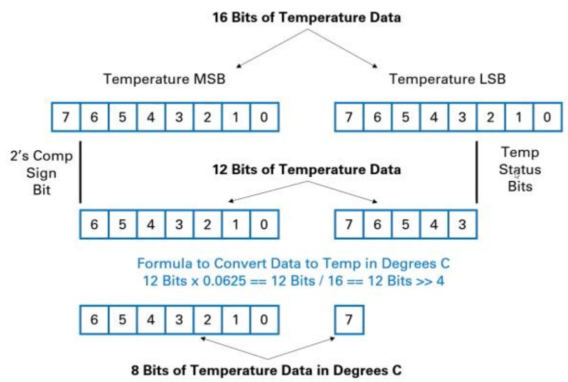

Fig. 6 Temperature data conversion flow

V. SIMULATION AND RESULTS

We used Vivado as the software tool to write and dump the Verilog code onto the Nexys A7 100T board.

The power analysis and Temperature value in seven segment display is shown in fig 4.5 and 4.6.

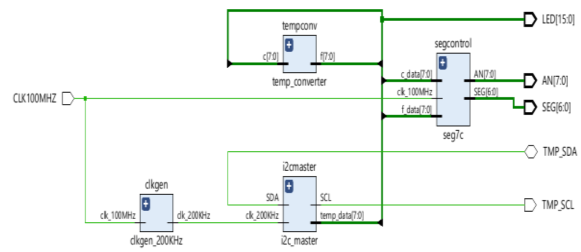

Fig. 5 Elaborated Design

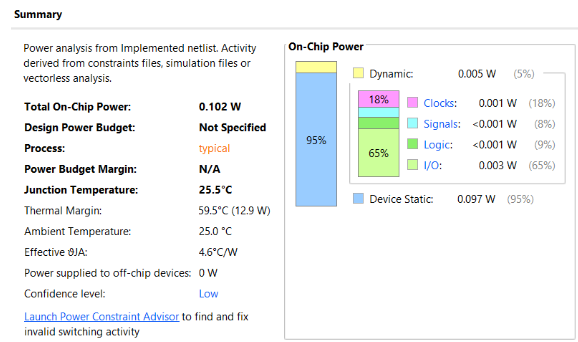

Fig. 6 Power analysis

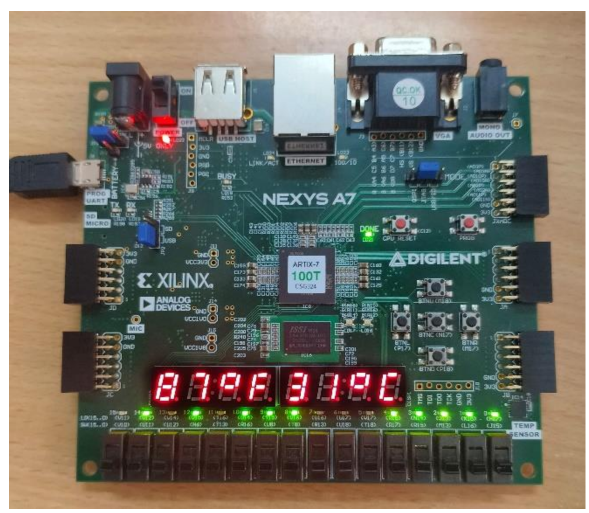

Fig. 7 Temperature value displayed in Fahrenheit and Celsius

V. CONCLUSION

In conclusion, the successful integration of the ADT7420 temperature sensor with the Nexys A7 FPGA development board highlights the potential of FPGA technology in temperature monitoring applications. By implementing an I2C master controller on the FPGA and utilizing Xilinx's design methodologies, precise communication with the sensor is achieved, allowing for accurate temperature readings in both Celsius and Fahrenheit scales. This project underscores the versatility and adaptability of FPGA platforms like the Nexys A7 board in real-world scenarios, where rapid prototyping and deployment of sensor-based systems are paramount. Moving forward, this innovative solution paves the way for further advancements in temperature monitoring and control systems across various industries, showcasing the inherent capabilities of FPGA technology in addressing complex engineering challenges.

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