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FPGA implementation of a Wide Range Precise Temperature Monitoring System

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Abstract – *In the presented paper a system has been designed which can be used to measure a wide range of temperature from -200˚C to 850˚C. The system consists of an FPGA which is a low cost, reconfigurable device and provides great flexibility to the system. The project employs a wide range Resistance temperature sensor Pt100 which detects the temperature and converts it into an electronic quantity, which is further amplified with the help of a Programmable Gain Amplifier. This signal is then fed into an Analog to Digital Converter which converts the signal into a precise digital signal. The controlling of all the peripherals is done with the help of an FPGA controller. An RTC has been employed in order to display the temperature in the LCD with a time stamp. Due to the wide range of the system it can be employed in a wide variety of applications.*

1. INTRODUCTION

Temperature monitoring system is one of the most widely used instruments in industries and researches for various applications. General purpose available commercial systems are very cheap but not precise enough for scientific applications. Performing accurate, high resolution, temperature monitoring is difficult and expensive and hence available specific scientific Instruments are very costly. Further the available instruments hardly have any rooms to customize and upgrade, as per user requirements.

Designed Embedded System for precise temperature monitoring using FPGA is an alternative and cost effective solution for scientific applications. It is possible to implement parallel hardware without operating system in a single FPGA that improves overall speed. The reconfigurability of the FPGA provides almost unlimited flexibility with easy up-gradability, which is most desirable in scientific environment. Unlike processors, FPGA based embedded systems provides next level of system integration. Most of the hardware is designed in FPGA using **V**ery high speed integrated circuit **H**ardware **D**escription **L**anguage (VHDL) which is easily portable and hence could be integrated along with other FPGA based system in which temperature monitoring is a part of the job.

Precise measurement of temperature has wide applications in scientific instrumentation and plays very important role. Designed temperature monitoring system would be used in the measurement of temperature over a large scale including cryogenic module subsystems as well as for Bio-medical applications like measurement of laser based absorption spectra of different oil and fat samples. Designed system is capable of measuring wide range of temperature with the accuracy of ± 0.02 °C at different points.

In the designed and developed system, **P**latinum **R**esistance **T**emperature **D**etector (PRTD) has been used as a temperature sensor because of its wide temperature range with relatively high accuracy as compared to other available temperature sensors. RTD has positive temperature co-efficient and its resistance changes proportional to temperature. To precisely measure the temperature using PRTD, 4-wire measurement technique has been adopted which eliminates the contact and wire resistance of the sensor. Constant current source of 1.234 mA has been designed and used for PRTD sensor excitation. Constant current source produces potential difference, of the order of mV range, across the sensor contacts proportional to the temperature. Programmable Gain Amplifier (PGA) has been used to further amplify this voltage difference. PGA provides the facility to tune the gain, suitable for digitization using ADC. Single chip, 4-channel, serial **A**nalog to **D**igital **C**onverter (ADC) has been used to digitized analog voltage signals corresponding to respective temperature sensors placed at different locations.

In the designed system FPGA has been used as a master logic controller. Inside the FPGA, various modules have been designed to control and processing of acquired digital data. Different modules and glue logic have been developed using VHDL, like ADC controller, PGA controller, UART communication, LCD Display Interface, RTC interfacing module, Digital filtering and temperature linearization etc.

1.1 Block Diagram of the system

ADC controller manages the digitized data of all the channels of ADC and facilitates to store in dual port RAM, designed inside the FPGA. PGA controller has ability to configure programmable gain through SPI interfacing. RTC controller communicates with Real Time Clock using I2C serial bus interface and stores the current time and calender information. UART controller sends the digitized and processed temperature data along with corresponding time of recording of the temperature to personal computer (PC) using RS-232 serial Interface.

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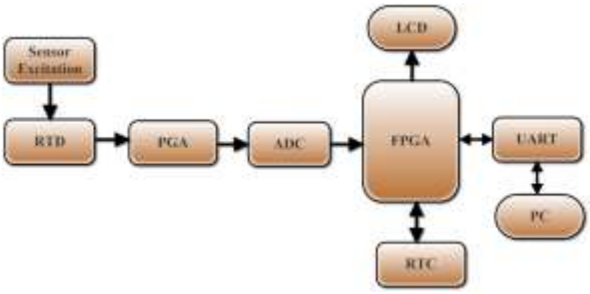

Figure -1: Block Diagram of proposed system

These controllers are designed using the VHDL programming language and implemented in single FPGA. Xilinx make, Spartan-6 series FPGA (XC6SLx9-TQ144-3I) has been used.

2. Implementation of various modules

The different parts of the project has been implemented at various submodule level and the final top model is then made by connecting all the submodules of the project. The FPGA plays a major role in the implementation on the system as well the submodules. The system has been implemented in Xilinx ISE and the language used is VHDL, which is a programming language that is used to describe hardware. It stands for VHSIC (Very High Speed Integrated Circuit) Hardware Description Language . It is intended for documenting and modeling digital systems ranging from a small chip to a large system. It can be used to model a digital system at any level of abstraction ranging from the architectural level down to the gate level.

2.1 Resistance Temperature Detector

In our project 4-wire platinum resistance temperature detector (PRTD) has been used to sense the precise temperature range from -200°C to +850°C. Platinum resistance temperature detectors that make use of the temperature dependence of a metal's resistance .RTD has positive temperature coefficient. The 4-wire PRTD compensate lead resistance between the sensor and measurement device. The platinum RTD temperature sensing element is the most accurate, linear and stable over time and temperature. RTD element is excited with 1mA of current source to avoid self-heating.

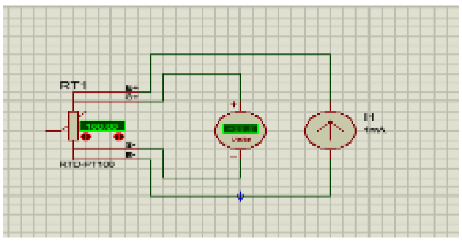

Figure -2: Implementation of RTD (4-wire Configuration)

2.2 PROGRAMMABLE GAIN AMPLIFIER (PGA)

Programmable gain amplifier implements an op-amp based non-inverting amplifier with user programmable gain. This amplifier has high input impedance, wide bandwidth, and selectable input voltage reference. LTC-6912 is a family of dual channel,low noise ,digitally programmable gain amplifier (PGA). The gains for both channels are independently programmable using a 3 wire SPI interface to select gains.

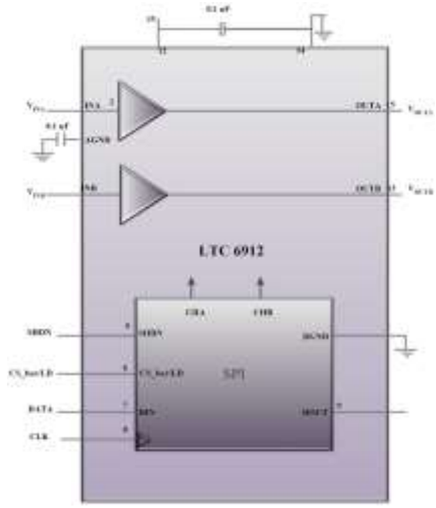

Figure -3: Block Diagram of PGA

The programmable gain amplifier is then implemented using a FPGA controller and is further simulated using Xilinx ISE simulator. The simulation results are shown ahead.

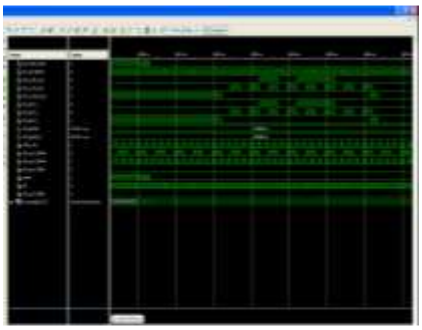

Figure -4: Simulation waveforms of PGA

2.3 ANALOG TO DIGITAL CONVERTER (ADC)

With the help of the calculations carried out to get the most accurate as well as precise result, we have to use a 16-bit ADC. Here we are using AD7606 as a 16 bit ADC. The AD7606 is 16-bit, simultaneous sampling, analog-to-digital data acquisition system (DAS) with eight channels .Each part contains analog input clamp protection, a second-order antialiasing filter, a track-hold amplifier, a 16-bit charge redistribution successive approximation analog-to-digital converter (ADC), a flexible digital filter, a 2.5V reference buffer, and high speed serial and parallel interfaces. It digitizes the analog data of temperature sensor after the signal conditioning. The received digital data of temperature sensor is then linearized and processed in FPGA.

Figure -5: Simulation waveforms of ADC interface

2.3 REAL TIME CLOCK (RTC)

In our project module DS1307 (RTC) is used to receive the real time details to monitor the temperature. Serial real-time clock (RTC) is a low power full binary-coded decimal (BCD) clock/calendar plus 56 byte of NV SRAM. Address and data are transferred serially through an I^2C, bidirectional bus. The clock/ Calendar provides seconds, minutes, hours, day, date, months and year information. The end of the months date is automatically adjusted for months with fewer than 31 days, including correction for leap year.DS1307 has in-built power-sense circuit that detects power failure and automatically switches to the backup supply.

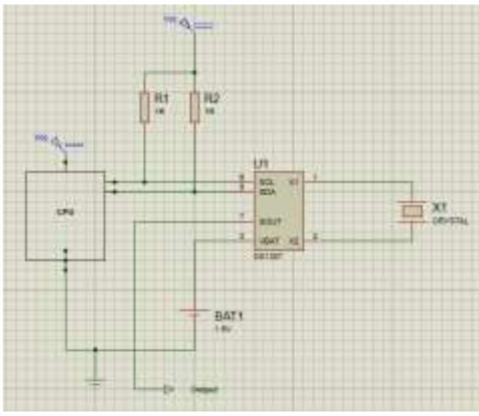

Figure -6: Operating circuit of RTC

3. CALCULATIONS

The input and output parameters of the selected components are further been investigated to match the required output. Some theoretical calculations for the component selection has been done which has been shown ahead.

3.1 Calculations for RTD:

We have the known values of:

Iref = 1.234 mA (constant current source)

VRTD = 0.137 mV and 0.141 Mv

R1 = 181.5 Ω

V1 = 0.224 Mv

Then,

Resistance of RTD due to room temperature

V1/V2 = R1/RRTD

(0.224)/(0.137) = (181.5)/RRTD

RRTD = 111.006 Ω

Resistance of RTD due to body temperature

V1/V2 = R1/RRTD

(0.224)/(0.141) = (181.5)/RRTD

RRTD = 114.247Ω

Calculation of RTD voltage at its minimum and maximum temperature value

At (-200ºC)

VRTD =RRTD* Iref

VRTD = 18.9(Ω) * 1.234(mA)

VRTD = 23.3226 mV

At (+850 ˚C)

VRTD =RRTD* Iref

VRTD = 390.26(Ω) * 1.234(mA)

VRTD = 481.58084 mV

Now, calculating RTD resistance at temperature T˚C

RTD(T) = RTD0* (1 + T* α)

RTD(T) = 100 * (1 + 0.02 *0.00385)

RTD(T) = 100.007 Ω

Calculating the RTD resistance difference at temperature T°C and 0°C

ΔR = RTD(T) – RTD0

ΔR = (100.007 - 100)˚C

ΔR = 0.007 Ω

Then the voltage difference for RTD will be

ΔV = ΔR *Iref

ΔV = 0.007 * 1.234

ΔV = 8.6 * 103 mV

ΔV = 8.6 μV

3.2 Calculation for selecting PGA

Since the output voltage from RTD is of the range of mV or μV so we need to amplify this voltage. For the amplification of voltage we have used PGA whose gain is programmable .For our requirement we select the value of gain equal to 10.

3.3 Calculation for selecting ADC

Gain of PGA = 10

Then the RTD voltage at (-200) ˚C with gain 10 is

VRTD = (RRTD* Iref) * 10

VRTD = (18.9(Ω) * 1.234(mA)) * 10

VRTD = 23.3226 mV

VRTD = 0.233V

The RTD voltage at (+850) ˚C with gain 10 is

VRTD = RRTD* Iref

VRTD = 390.26(Ω) * 1.234(mA)

VRTD = 481.58084mV

VRTD = 4.816V

And the voltage difference for RTD with gain 10 will be

ΔV = (ΔR * Iref) * 10

ΔV = (0.007 * 1.234)* 10

ΔV = 86 * 103 mV

ΔV = 86 μV

From above calculations we conclude that the voltage range of ADC should be of 5V.Our requirement is to resolve voltage of 86μV. So the resolution of ADC should be of 86 μV. A 16-bit ADC fulfils these requirements.

4. RESULT AND CONCLUSION

The implementation of the real time temperature monitoring has been successful. The RTL view and the Synthesis report of the proposed system is shown ahead.

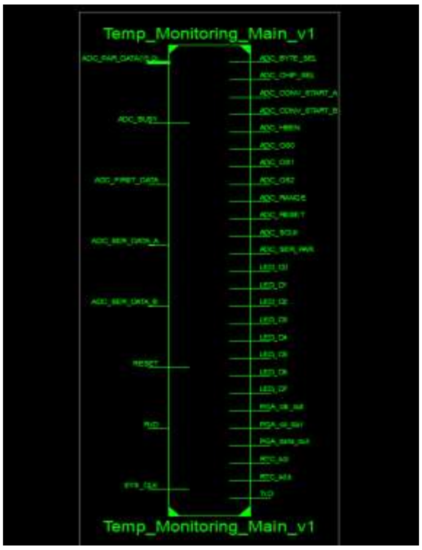

Figure -7: RTL view of proposed system

Temp_Monitoring_Main_v1 Project Status			
Project File:	[illegible]	Parser Errors:	No Errors
Module Name:	Temp_Monitoring_Main_v1	Implementation State:	Synthesized
Target Device:	[illegible]	•Errors:	No Errors
Product Version:	ISE 14.7	•Warnings:	[illegible]
Design Goal:	Balanced	•Routing Results:	
Design Strategy:	[illegible]	•Timing Constraints:	
Environment:	System Settings	•Final Timing Score:	

Device Utilization Summary (estimated values)			
Logic Utilization	Used	Available	Utilization
Number of Slice Registers	[illegible]	11440	2%
Number of Slice LUTs	174	5720	3%
Number of fully used LUT-FF pairs	112	[illegible]	[illegible]
Number of bonded IOBs	[illegible]	102	[illegible]
Number of Block RAM/FIFO	2	32	6%
Number of BUFG/BUFGCTRLs	4	16	25%

Figure -8: Synthesis report of proposed system

The proposed system has a wide range of temperature sensing capability which ranges from -200˚C to 850˚C. The system shows a good response but can further be linearised to get a linear relationship between temperature and resistance. The system also shows a good precision of almost ±0.02˚C.

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