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Development of FPGA Based Multi-Channel Temperature Controller using Thermistors for under Water Vehicles

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Abstract*: Under water vehicles with electrical propulsion such as underwater autonomous vehicles are designed to propel with high energy batteries. These batteries are the main source of power to motor and other electronic subsystems. Temperature of the batteries is one of the critical parameter that gives the information about the health of the battery and whether the battery is able to deliver the required power to other subsystems. In case of any abnormality such as battery short circuit or other reasons, the temperature of the battery may shoot up to the alarm levels at various places of the battery and other sub sections near to the battery because the temperature is transferred from battery to the nearby shell and other subsystems. For this application, Multi-channel temperature controller is designed, verified and tested in the battery assembly. The proposed system can monitor and control up to the 32 temperature channels by integrating thermistors in the complete test set-up and it is designed in such a way that the battery is disconnected from the other subsystems in case of any abnormality or temperature is increased beyond the safety limit. In this paper, design, calibration and integration and testing of multi-channel Temperature controller using FPGA with thermistors is discussed and the system has internal memory and it can store the temperature at various channels in flash memory so that the system is well suited for not only self-controlled underwater vehicles but also thermal engine based systems. The system can also monitor and control the temperature in harsh environment even also in industrial applications. The system is designed in Spartan 3FPGA using VHDL and verification of the design is done Xilinx chip-scope-pro. The front end Graphical User Interface (GUI) is designed for online monitoring, data downloading and processing using visual C++ and MATLAB.

Index Terms: Multi-channel Intelligent temperature controller, FPGA based system, Thermistors, Battery controller with onboard systems, Battery monitoring system, Data Acquisition Systems, Graphical User Interface (GUI).

1. INTRODUCTION

The battery system performance is mainly dependent not only on the conditions where the system is able to deliver the power but also on other subsystems. In Autonomous vehicles and under water vehicles high energy batteries are the main sources of power to electrical propulsion systems and other subsystems. Some of the critical parameters are required to be monitored continuously to get the health status of the subsystems. Temperature is the main critical parameters of the battery to be monitored continuously. Any vehicle which involves the interconnection of many subsystems with inter wiring requires the locations where the abnormality or any failures are to be identified for proper fixing of the temperature sensors for continuous monitoring. The temperature sensors are mounted properly on the shells without any damage or any malfunctioning. Proper care has to be taken in fixing the temperature sensors and wiring is to be done so as to minimize the signal loss. Thermistors are the best choice for measuring the temperature in such vehicles for monitoring and controlling. Thermistors are interfaced to temperature acquisition system in which signal conditioning circuits are designed in such a way that the resistance with respect to temperature is to be converted into proper voltages that are given to Analog to digital converters. The converted voltage should be within the limits of input voltage ranges of the ADC. FPGA is the main controller for acquisition and monitoring of temperature channels [3]. The structure of this paper is as follows. Section 2 gives brief overview and describes the sensors and interfacing and signal condition circuit. Section 3 describes the hardware implementation details of the System and Section 4 describes the implementation of HDL software and simulated results of the modules. Section 5 gives the details of the test setup carried out along with the test results. Section 6 concludes the topic.

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II.SENSORS AND SIGNAL CONDITIONING DESIGN

Sensor is the main device that is used to sense the environmental parameters to act as a bridge between the environment and measured instrumentation systems. The selection of temperature sensor is mainly dependent on the environment we are working and the range of temperature to be measured. Thermistors are used for measuring temperature is Negative temperature coefficient (NTC) type sensors in which the resistance of the sensor is decreased by increasing in temperature .For this type of applications in measuring battery shells temperature, thermistors are mostly suitable because the measured temperature range is with in less than 200 oC and these sensors have faster response, accurate and very economical. The thermistors are mounted on the battery and other subsection shells. Thermistors are having highly nonlinear characteristic curves. The resistance is generally exponential function of temperature.

$$\ln\left(\frac{R}{R_0}\right) = \beta\left(\frac{1}{T} - \frac{1}{T_0}\right)$$

Where R0 is the resistance at a reference temperature, T0, while β is a constant characteristics of the material. The thermistor is embedded into the circuit so as to generate corresponding voltage.

A. Thermistors

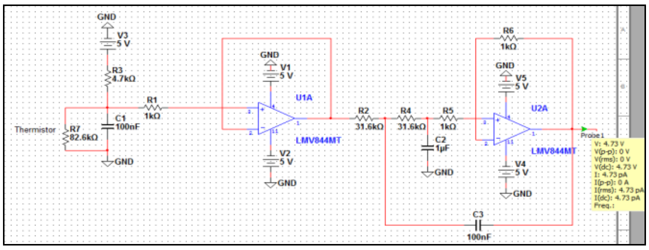
Thermistors used for the measurement of temperature are 100K at 25 oC with Negative Temperature Coefficient type. These sensors can be used in the temperature range of -20 oC to 250 oC [5]. It has thermistor chip welded with leads by alloy soldering process and partially treated by glass sealing for protecting the sensing element from harsh and heat environments. The element has a bead with good stability, small size and rapid response used in temperature measurement applications. It has thermal time constant less than 5sec and beta value 3950±1% calculated from resistance between 25 oC to 50 oC. These sensors are calibrated as per the test requirement. The sensors are mounted on the battery shell surface with the help of thermo tape along with seal to firmly fix on the surface where the temperature is to be measured.

"Fig1." Mounting of sensors

B. Signal Conditioning circuits

Sensors generate the resistance variation based on temperature. Signal conditioning circuits are designed in such a way that the resistance variation is converted in to the corresponding voltage values being measured. The voltage obtained by the sensor should be within the range of ADC input voltage. It is accomplished by voltage divider circuit or any bridge circuits. Simple voltage divider with 4.7KΩ pull up resistor along with a unity gain circuit with low pass filter is designed, tested and implemented. The cutoff frequency of the filter is basically determined by the temperature rising of the test system. In fact, the variation of temperature is not exceeding 5Hz. The noise induced in the measurement systems contains high frequency noise which can be filtered by low pass filter and its cut off frequency is set to be 15Hz.

The signal conditioning circuits are designed and simulated using Multi-Sim software and verified for its functionality. The circuit gives 4.77V at temperature of 25 oC with cutoff frequency of 15Hz.



"Fig2." Signal Conditioning circuit design

III.CONTROLLER HARDWARE

The block diagram of temperature controller based on FPGA is shown in below Fig.3. Signal conditioning circuit output is given to Analog to Digital converter which is fast, single supply, simultaneous 16bit ADC. Spartn-3E FPGA controls all the peripherals and stores ADC data to Block RAM [2]. FPGA is configured to operate in SPI serial Flash mode. For every power on, FPGA is booted from serial Flash. USB is also interfaced to FPGA for establishing serial communication to PC. Thermistor output resistance is converted into voltage by signal conditioning circuit are given to ADC. The converted digital data is stored in Block RAM and data is written to NAND Flash as page wise and the same digital converted data is applied to the controller module in the FPGA. Total 16 temperature channels are routed to FPGA and critical channels temperature data is continuously monitored and stored. If any of the abnormality in temperature is found, then the corresponding battery module is switched off by relay.

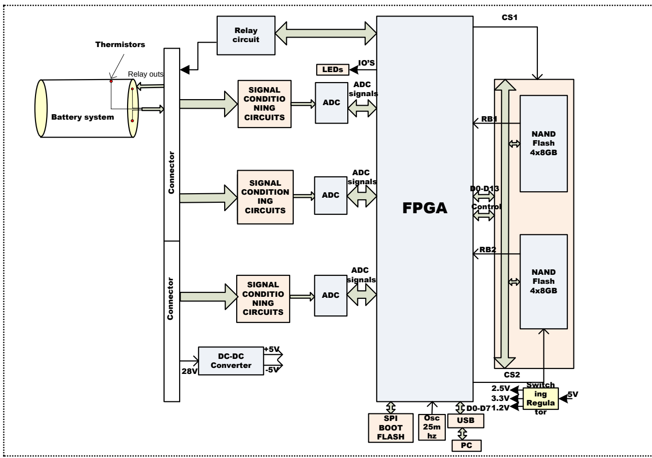


Fig.3.Block diagram of FPGA based Temperature controller.

The AD7655 is a simultaneous sampling, 1Mbps, dual channel and 16 bit analog to digital converter that operates form a single 5V supply [6]. It contains two low noise, wide bandwidth, track and hold amplifiers that allow simultaneous sampling, and supports serial and parallel system interface ports. It is configured to take input voltage range from0 to 5V and in SPI mode.The FT245R is a USB to parallel FIFO interface device which simplifies USB to FIFO designs and reduces external component count by fully integrating an external EEPROM,

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USB termination resistors and an integrated clock circuit which requires no external crystal, into the device[8]. The temperature data can be transferred to PC test station using USB FIFO.

IV.MPLEMENTATION DETAILS

FPGA, being the main controller, generates the necessary control sequence for all the devices interfaced. It starts ADC acquisition and reads the data after conversion along time stamp values and stores it in the block RAM [5]. When allocated BRAM memory is filled, then data is read from BRAM and sends to USB FIFO. FPGA programming is volatile in which the data is lost when the supply voltage is turned off. With every power on, FPGA is programmed by loading data into robust, reprogrammable Nonvolatile device. It is configured in Master SPI mode using serial flash PROM. Temp Control Module which takes the temperature values as inputs and compare the temperatures are within the limits or not. If any rise in temperature is found, it automatically shut down the battery modules. The solid state relays are used for isolation of batteries from other subsystems.

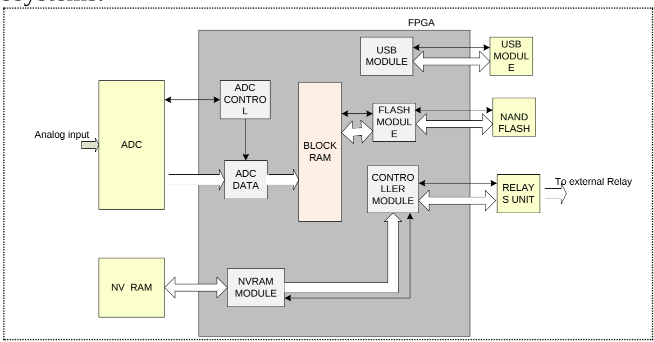


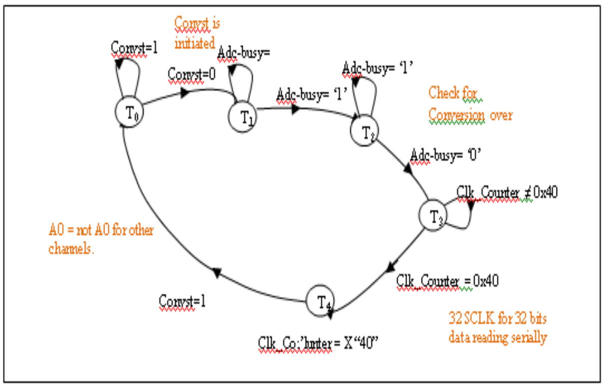
Fig.4.FPGA modules implemented.

A. Analog to Digital Converter

ADC provides the user with two on chip, track and hold successive approximation ADCs that do not exhibit any pipeline or latency, making ideal for multiple multiplexed channel application. It can be used as a 4- channel ADC with two pairs simultaneously sampled. The AD7655 can be operated from a single 5 V supply and be interfaced to either 5 V or 3 V digital logic. The AD7655 features two modes of operation, normal mode and impulse mode. Each of these modes is suitable for specific applications. Maximum through put for the ADC is 1MSPS in normal mode. It can be interfaced with the host system by using either a serial or parallel interface. The serial interface is multiplexed on the parallel data bus. It is designed to operate in serial mode.

The AD7655 is configured to use in the slave serial interface when the SER/PAR is held high. The AD7655 outputs 32 bits of data, MSB first, on the SDOUT pin. The order of the channels being output is also controlled by A/B. When high, Channel A is output first; when low, Channel B is output first. This data is synchronized with the 32 clock pulses provided on the SCLK pin.

The control flow of the ADC which is implemented in VHDL [1] is shown in Fig 3. Each ADC chip has got four channels and conversion start signal is required for ADC to start conversion. ADC sampling required for all channel is to be at 100 KHz. For every conversion start, ADC gives out two channels of data serially. So conversion start frequency will be 200 KHz to read out four channel data.



"Fig.5." ADC control sequence

For every 5μs, conversion signal must be initiated. When it goes to T1, conversion is initiated and goes to T3, after conversion is over. Two channel data is read from SDOUT pin from MSB to LSB by 32 clock pulses. When the ADC data available signal is High, then ADC data is written to the Block RAM.

B. Control Module

Total 16 channel temperature data is converted in to digital format and among these 16 temperature data four of the temperatures are very critical and compared with the threshold values kept in the look up table. If any of the values are exceed the threshold value, then the battery cells are isolated by corresponding relay.

C. NAND Flash

The NAND08G are nonvolatile flash memories with density of 8Gbits. Each page in NAND Flash is 2048 bytes. Flash module in FPGA initiates BRAM Read signal, when BRAM is full and necessary control signals for writing data to NAND Flash [9]. Page programming is done for flash by writing initial command, address in five cycles and data of 2048 byte and confirms command. For every page program, page address, block address and time stamps are saved into EEPROM. Flash erase is done by giving erase command through USB. It is also interfaced to USB module for establishing communication between FPGA and USB.

D. Download Mode

The FT245R is a USB to parallel FIFO interface device which simplifies USB to FIFO designs and reduces external component count by fully integrating an external EEPROM, USB termination resistors and an integrated clock circuit which requires no external crystal, into the device. Different commands are given to the system for data downloading and data erasing [11]. USB module gives read command to the NAND Flash for data downloading through Flash module.

When RD command is given to the NAND Flash, data in NAND Flash is written to the BRAM and placed in the USB FIFO that makes the Flag RXF set. Once the data is ready in FIFO, It is read and kept in one file in the host computer.

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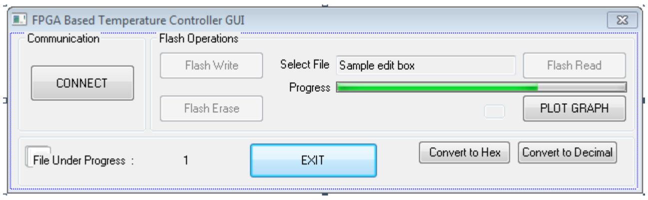
E. Graphical User Interface

Graphical user interface is developed in visual C++ for interfacing the Temperature controller to PC based test station. GUI is designed to give commands to system for flash erase for memory erase, flash write to initiate the temperature acquisition and controlling, and flash read for download the processed data from system to Personal Computer. It can also provide the offline processing of downloaded raw data into creation of formatted hex value files and data value files.



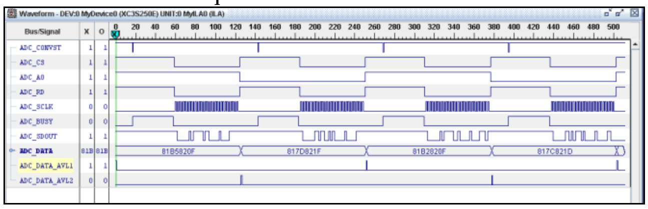
"Fig.6." Graphical User Interface

V.TEST RESULTS

Total 16 No of thermistors are placed on each module of the battery section and other positions on the vehicle where the temperature is to be monitored. The developed system can be able to cater 32 temperature channels and among these channels, only sixteen channels are used as per the requirement. These thermistors are fixed firmly as shown in Fig.1 and connected to Temperature controller unit. When the system is powered on, by default, it goes into temperature acquisition mode in which it acquires temperature data and process the data of various channels for any abnormalities. The battery power source to load connection is isolated by operation of relays to switch off faulty batteries based on the various temperature channels data. The temperature data is stored in NAND flash memory and it is retrieved back to test station through universal synchronous Bus (USB) as raw data file. The raw file along with the status flags of various battery modules is processed in offline processing software to create the formatted hexadecimal files and converted engineering value files.

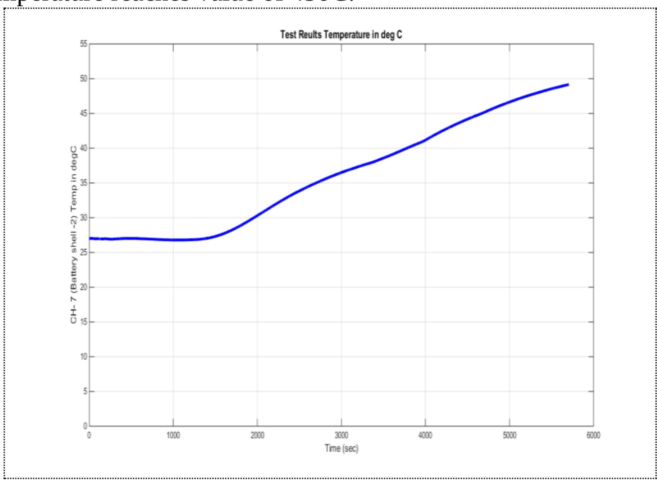
"Fig.7." Temperature Controller system

Signal conditioning circuit is designed and verified using multi-sim tool and the hardware is implemented and tested. Thermistors are temperature sensitive devices so that the input resistances are varied and output voltage is observed. The output voltage is applied to low pass filter and output of low pass filer is given to ADC. FPGA is the main controller and it initiates ADC conversion and checks for conversion complete. The ADC is configured in SPI mode and clock is generated for serial clock is generated from FPGA main clock of frequency 25MHz. all modules are designed and developed in VHDL using Xilinx ISE and debugging is completed in Chip-scope Pro tool. The following figure.7 shows the Chip-scope outputs of ADC control module for acquisition of ADC data.



"Fig.8" Chip-scope outputs for ADC control flow

To write the data into the each page into the Flash, It is required to store the data of 8192 Bytes of data into the Block RAM temporarily. ADC acquired data along with the time stamp is saved onto the Block RAM and once it is filled and it is to be written into the NAND Flash. The temperature values of different channels are given to controller module and these values are compared with the threshold values. If any of the battery module temperature shows abnormality, then FPGA switches off the battery module. The stored data in the Flash memory can be downloaded via USB communication using user friendly GUI in Visual studio. After downloading data, the graphs for different temperature channels are plotted using MATLAB software to analyze the battery performance during test. The below plot shows the temperature values of one of the channel mounted on the one battery module and its temperature reaches value of 45oC.



"Fig.9" Plot for Temperature parameter.

The below table shows that the maximum temperature values recorded during testing for only five important temperature channels.

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S. No	Channel No	Temperature (in ºC)	
1.	Ch-01	26.9	49.1
2.	Ch-02	26.1	35.3
3.	Ch-03	27.1	40.2
4.	Ch-04	26.3	41.6
5.	Ch-05	26.2	39.2

"Table.1." Temperature values for five channels.

The test is conducted for duration of 5700sec and critical temperatures are recorded. Temperature of channel one is increased to 49.1 oC.

VI. CONCLUSION

The Temperature controller is developed and tested and the system provides a powerful capability for measuring and controlling various temperatures of underwater vehicles at different locations. The system is not only suited for the missile applications in testing of electrical batteries but also in vehicle engine designs. The system can also support to use in remote or indigenous systems because it has high memory storage for long endurance trials. It has internal solid state relays to control on and off various battery modules in case of any abnormalities. The main controller is an FPGA and the design is implemented and tested in VHDL using Xilinx ISE. A GUI has been created in Visual studio for online monitoring, processing and downloading the data. The obtained graphs are plotted in MAT lab. This is one of the best economical solutions for battery performance and electrical engine endurance tests.

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