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Design of Low Cost Industrial Temperature Transmitter

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***Abstract*—**In today's industrial scenario, the temperature transmitters are one of the most widely used field devices, with innumerable functionalities and features. According to a market research study, majority of the industries use temperature transmitters to monitor and control their processes. These temperature transmitters are costing very high in the market. Even the maintenance of these transmitters is costly. Keeping in view of the above aspect, this project is aiming to design a low cost temperature transmitter. The project proposes to use inbuilt 10 bit ADC and convert it to 16 bit ADC using oversampling method. Temperature transmitter's role is to isolate the temperature signal, filter any Electro- magnetic noise, amplify and convert to 16-bit resolution of input process value.The retransmission part will consist of voltage to current conversion integrated circuit to produce 4 to 20mA current. It is required to take care of the non-linearity of some of the sensors by using Transmitter that can linearize the electrical signal, process and re-transmit them in form of a desired electrical signal which is generally industrial standard 4-20 mA. A low cost Programmable Universal Temperature Transmitter will be designed for temperature sensors like RTD and Thermocouples. Design and simulation of a closed loop control system for 4 to 20mA current loop will be carried out. It is proposed to use analog components for signal conditioning and Renesas make Microcontroller for further computations. In the last a Modbus Communication protocol will be introduced for communication between Field device and PC.

Keywords-*Oversampling, Polynomial Linearization,Digital Filtering,Universal input, Retransmission and Field Device.*

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I. Introduction

A temperature transmitter is an embedded device in which temperature sensors (Like: RTD, Thermocouple) are interfaced to measure or to control devices. Sensors like RTD and thermocouple which can convert non electrical parameters (like temperature) signals into electrical signals in accordance with the measured input quantity. Now this sensors need a device called transmitter that can linearized the electrical signal from them process and then re-transmit them in form of a desired electrical signal. Which is generally follows industrial standards: 4-20mA current loop.

In this paper, we describe the implementation of an Universal temperature transmitter for a 4-20mA current loop system. In a 4-20mA current loop, the 4mA value represents the minimum output value and 20mA represents the maximum output value of the sensor. It is proposed to use analog components for signal conditioning and R5F100FCAFP Renesas Microcontroller (MCU) for further computations. ADC10(10-bit analog to digital converter) is converted in to 16-bit by oversampling method. The first part of the temperature transmitter is to convert the physical data (non-electrical signal) of temperature into electrical signal, through the A/D converter. Than this digital signal goes to the microcontroller R5F100FCAFP which measure signal and give exact Temperature value. This measured temperature value is transfer to the control room by the second part of communication through the Modbus.

This device used the Modbus RTU mode communication protocol to read temperature value from device and to configure device parameter. It is the application layer protocol. This protocol used for communication between system and field.

II. Design of the system

In this paper, we describe the implementation of an RTD and Thermocouple temperature transmitter for a 4-20mA current loop system. The temperature transmitter is used for measuring the temperature. It converts the temperature signal into Industrial standard 4-20mA current signal in its output.There are two parts of this system design. First is the temperature sensor sense the non-electrical (Temperature) signal and convert it into electrical signal. And second part is the temperature transmitter takes the electrical signal from the sensor and make it into desired Standard 4-20 mA Current oop..

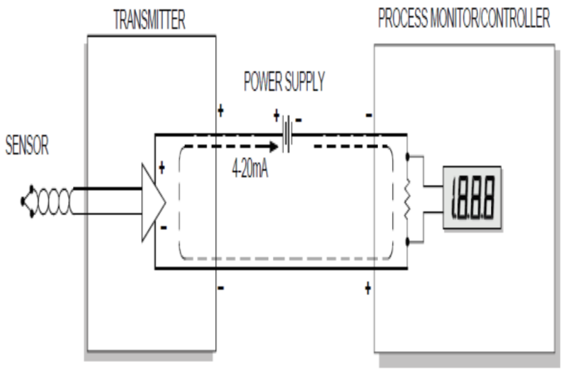

Figure 1. Industrial Standard 4-20ma Current loop

The DC power supply provides the power to the system. The transducer regulates the flow of current through the wires Do not mix complete spellings and abbreviations of units: “Wb/m2” or “webers per square at 4 to 20mA, where 4 mA represents a live zero signal and 20 mA represents the maximum signal.

III. DESIGN OF THE HARDWARE

A. *Hardware flow for RTD/Thermocouple Temperature Transmitter*

The temperature transmitter is most widely used in the industries for measuring the higher and lower temperature signal.In the case of temperature transmitter, the challenge is to provide various types of Industrial Temperature sensors like RTD 3Wire, RTD 4 Wire, Thermocouple E,J,K,T,B,R,S,N, Ohm, mV. In this paper the goal is to provide universal input and make cost effective solution. The proposed temperature transmitter and signal conditioning circuit design in single chip by using R5F100FCAFP. Biasing of the voltage controlled current source is carried out using the on-board PWM. This design does not required the external ADC chip.

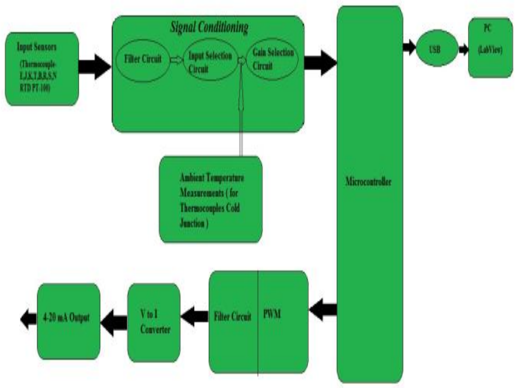

Figure 2. Hardware Flow RTD/TC Temperature Transmitter

In this paper, Loop powered helps reduce wiring cost, Universal Input helps reduce inventory cost, and Galvanic Isolation reduces measurement errors and provide protection from field surges.

B. *Digital Circuit Design*

- R5F100FCAFP is the embedded microprocessor which has following features
- It is a Renesas Make16 bit MCU RL-78 core
- Inbuilt 10 Bit ADC, Lower Power Mode Operation
- PWM Timers, Watch Dog Timer
- Data RAM 2KB
- Max Clock frequency/speed is 32 MHz
- Core size/Data bus width is 16 bit
- Flash/Program memory is 32KB
- Number of i/o is 40
- Operating supply voltage is 1.6 V to 5.5 V
- Operating Temperature is +85 ºC to -40 ºC

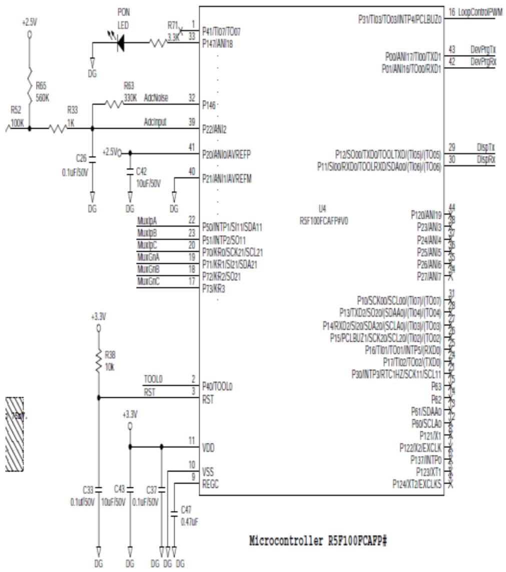

Figure 3. Digital Circuit

C. *Oversampling*

The main goal of this paper is to make Cost effective temperature transmitter by using oversampling technique.

Oversampling is one type of the sampling process in whichaInformation signal is sampled at higher frequency.It is higher than the Nyquist rate. So by using oversampling technique we can convert 10 bit ADC to 16 bit ADC.Aftercompleting Amplification section of the system extra High frequency noise (amplitude must be higher than ADC voltage resolution) is added to amplified sensor signal for oversampling and achieve more accurate result. For example converting 10-bit ADC resolution to 16-bit resolution ADC using oversampling must be High Speed and then Oversampling signalwill be added in to amplified signal and sampled reading sum with each other and averaging provide 16-bit reading. The frequency of the Oversampling signal is 4^n times of the nyquist frequency. Here the Resolution and speed of 16 bit ADC is higher than the 10 bit ADC.

Below equation is implemented for n bit resolution,

- Over sampling frequency = $4^n * F_{nyquist}$.
- Converting 10 bit ADC to 16 bit.

Required bit data

$$=\frac{(2^{10}\ bit\ data) + (2^{m}\ \ bit\ oversampled\ data)}{2^{m-n}}$$

Where,

n= No. of extra bit required for High Resolution

m = Sampled Time

ADC10 (10-bit analog to digital converter) is converted into 16-bit by using oversampling method. In this paper, we used Oversampling Technique for converting 10 bit ADC to 16 bit ADC and make it cost effective temperature transmitter.

IV . THE DESIGN OF SOFTWARE

In the software design, the software program of Temperature transmitter includes mathematical

program and modbus communication Program. The system software is designed in Cube suit+(Software) by c language. The software program is stored in the interior flash memory of R5F100FCAFPrenesas microcontroller.

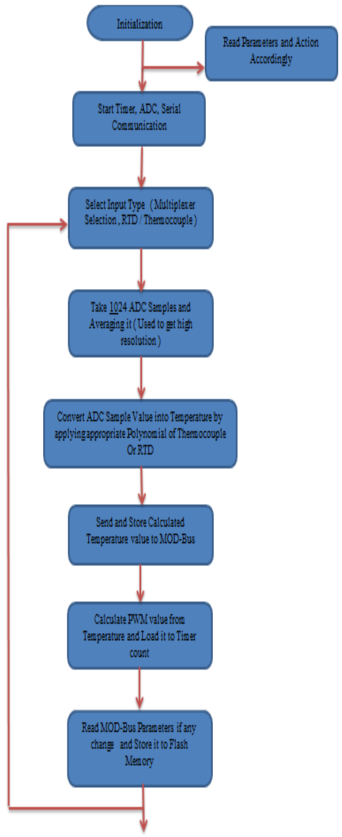

Figure 4. System Flow

In this ,we describe the implementation of an RTD and Thermocouple temperature transmitter for a 4-20mA current loop system. The temperature transmitter is used for the measuring the temperature.

V. Testing

The GPB (General Purpose Board pcb) used for the practical experiment. K type Thermocouple used for the testing the system.

A. *Modbus and Hardware Testing*

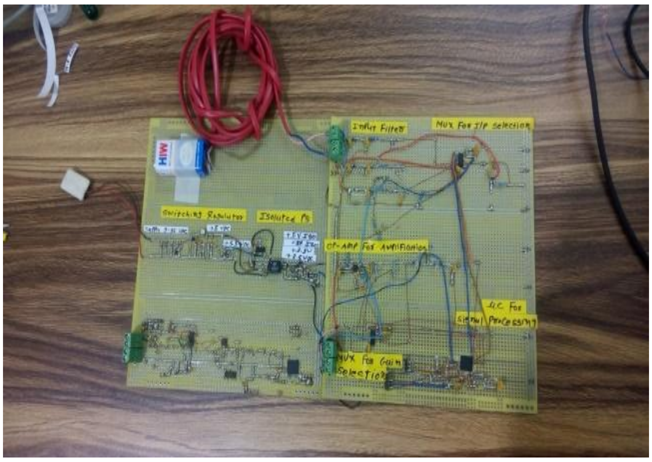

Figure 5. Experimental Hardware on GPB

MODBUS is an application-layer protocol based on a Master-Slave client/server or request/reply architecture. Here the Modbus is connected to computer through the virtual serial port. The computer sends a request frame to the temperature transmitter by the Modbus tester software, the temperature transmitter receives the request frame on the bus, then transmitter sends responsive frame within the response time.

Output

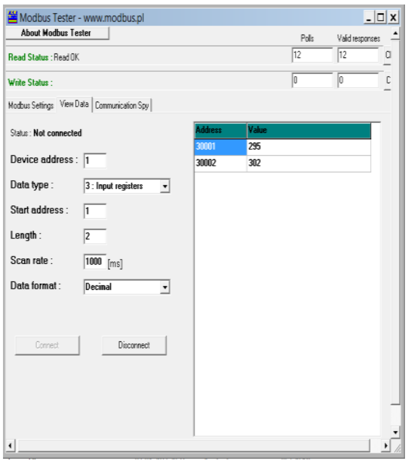

Figure 6. Modbus tester

By using this software we can select the input type of temperature sensors so that temperature transmitter can know the range of the input sensor. In the Input type section we can manually change the input type from the RTD and thermocouple (E,J,K,T,B,R,S,N) so that we have to set up the modbus parameter first. After selecting the input type of the sensor we can start the communication between the master and slave. Here slave (temperature transmitter) sends the actual data of the field to the master (computer), and by this data configuration software we can see the process value of the field.

VI. CONCLUSION

The Programmable Universal Temperature will be designed with low power consumption. The ultra-low power microcontroller is taken as a heart of the system. Design and simulation of a closed loop control system for 4 to 20mA current loop will be carried out. Minimum RTD current source is achieved. Component selection and Circuit design is achieved to meet the Universal Temperature Transmitter power requirements.

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