2 Wire And 3 Wire, 4-20mA Current Loop Isolated Temperature Transmitter

Raj Kanabar
P.G Student (Communication Systems Engineering)
L.J. Institute of Engineering & Technology,
Ahmedabad, India
rajkanabar74@gmail.com

Dr. Anilkumar Suthar
Director and Guide (Communication system Engineering)
L.J. Institute of Engineering & Technology,
Ahmedabad, India
sutharac@gmail.com

Abstract— **A low cost solution is designed for a typical RTD and thermocouple temperature transmitter for a 2-wire and 3 wire 4-20mA current loop system. The design circuit has analog components and R5F100FCAFP microcontroller. The RTD constant current source is made by operational amplifiers on the device. Biasing of the current source was carried out via a loop control PWM pin and converted in to current source by analog components. 16-bit resolution of input value is achieved by over sampling method. The signal conditioning of the sensed RTD value was carried out via a differential OA of incorporating on-chip analog components. Temperature transmitter is transmitting data based on the Modbus(RTU) protocol, Transmitter solution provides more flexibility due to the additional processing enabled by the R5F100FCAFP microcontroller. This allows linearization through software for the display of measured values. (Retransmission of Two sensor signal in 4-20mA is provide in this device).**

Key Words— **4-20mA Current Loop, Renesas R5F100FCAFP Microcontroller, Modbus Protocol.**

I. INTRODUCTION

Current loop communication solutions are used in industrial application The 4-20 mA current loop is a very robust sensor industrial standard. Current loops are more suitable for data transmission because of inherent insensitivity to electrical noise. These current loops are used to transfer sensed output response from various sensor solutions over a distance, sometimes thousands of meters away. The transmitter is the heart of the 4-20 mA signaling system. It converts a physical properties like temperature, humidity or pressure into an electrical signal. This electrical signal proportional to the temperature, humidity or pressure. In a 4-20 mA loop, 4 mA represents the low end of the measurement range and 20 mA represents the high end.[1] Various sensors(RTD, thermocouple) are available which convert non-electrical parameters like temperature, humidity, pressure, fluid level etc. into electrical signals in accordance with the measured input quantity.

The inherent non-linearity of these sensors need an instrument called Transmitter that could linearize the electrical signal from them, process them and retransmit them. The linearity of the output response is tied to the sensed value of the sensor integrated with the current loop. In a 4-20mA current loop[2]. In this paper, we describe the implementation of an RTD, thermocouple(E,J,K,T,B,R,S,N)and mV input range. temperature transmitter for a 4-20mA current loop system. This design leverages the on-chip analog components on the R5F100FCAFP microcontroller (MCU) from Renesas Electronics to implement a single chip solution to carry out both the signal conditioning and the voltage controlled current transmission. This cost-effective solution also provides for additional flexibility by enabling further signal conditioning and linearization of the sensed response through the use of the CPU on the microcontroller by using Modbus protocol.
Multisim simulations are compared to the actual circuit response.

II. DESIGN OF THE SYSTEM

This transmitter is used for the measuring the temperature. It can change the temperature signal into 4-20mA current signal in its output. This system is design in two parts. 1st part includes the temperature sensitive device, the signal conditioning module and 2nd part is two wire system V/I translation circuit and PWM to current conversion without using external DAC . There is inbuilt ADC in the MCU

In most of the systems, The sensing and transmitter circuits are managed by additional embedded analog products while the MCU is used as a communication buffer between the sensing side and the digital to analog conversion side. Constant current source circuit was designed to measure the voltage of resistance temperature detector (RTD)

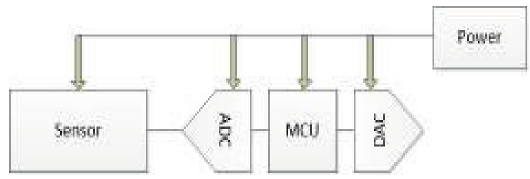


Figure 1: Block diagram of basic temperature transmitter

III. Reference Design

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 circuit is based on the concept of two-wire system which provides itself electric power with 4-20mA current signals. This design is consisted of 3 parts. The temperature sensitive device, the signal conditioning module, the two wire system V/I translation circuit .

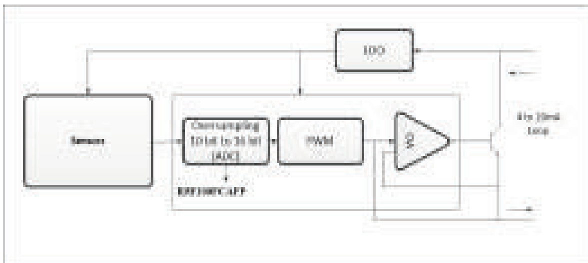


Figure 2 : Block Diagram For TT7S Design

The temperature sensitive device transform the physical quantity of temperature in to electric parameters and then signal conditioning circuit magnifies, conditions and transforms the small or non-linear electrical parameters from the device into linear voltage for output and according to its output the two-wire system V/I translation circuit[3] controls the overall electricity, it obtains the voltage from the loop circuit .

After Amplification section extra High frequency noise (amplitude must be higher than ADC voltage resolution) will added for oversampling and achieve more accurate result. Over sampling frequency = 4n * $F_{nyquist}$ [4-5]. For example converting 10-bit ADC resolution to 14-bit resolution ADC must be High Speed and Oversampling signal will be added in to amplified signal and sampled reading sum with each other and averaging provide 14-bit reading. Below equation is implemented for n bit resolution,

Required bit data =

$$\frac{(2^{12}\text{ bit data}) + (2^{m}\text{ bit oversampled data})}{2^{m-n}}$$

Where,

n= No. of extra bit required for High Resolution
m = Sampled Time

ADC10 (10-bit analog to digital converter) is converted in to 16-bit by oversampling method. a 16-bit timer, and integrated op amps which are well suited for driving a current loop application. LDO providing a constant 3V source. The R5F100FCAFP utilizes and integrated op amp(OA) to take the now DC voltage source supplied by the PWM to provide a current source for the loop[5].

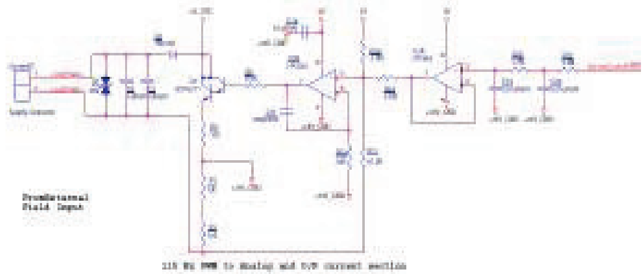


Figure 3 : PWM to analog and o/p current section

A. RTD constant current source

An RTD requires a known constant current source[6-7] for the RTD's excitation to produce a useful voltage output proportional to the resistance of the RTD sensor. The resulting output voltage is then amplified and fed to an ADC for measurement. In this method, RTD current should be minimized to avoid self-heating. In general, approximately 1 mA or less current is used.

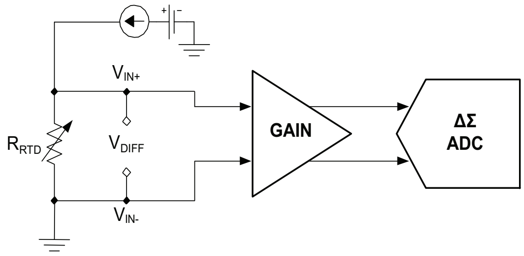


Figure 4 : RTD constant current source

- Irtd out = Vin*R3
- R2*R5
- So Irtd out mathematically= 0.25 mA
- In simulation result Irtd = 0.211 mA.
- And practically current is Irtd = 0.208mA

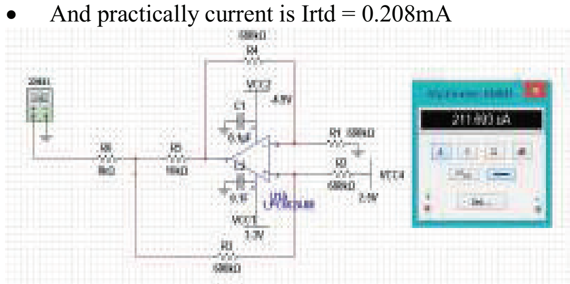


Figure 5 : Simulation result for Irtd current source

B. Secondary side supply

Power supplies for 2-wire and 3 wire transmitters must always be DC. Secondary side supply is made by external IC. Which will give 5V DC and 24V DC supply. For 4-20 mA loops with 2-wire transmitters, common power supply voltages are 36 VDC, 24 VDC

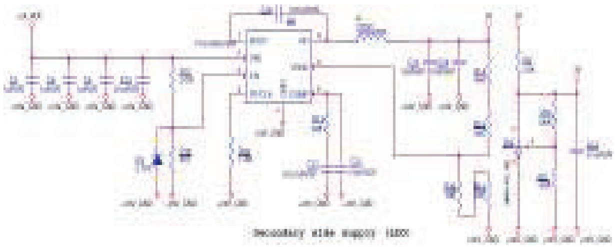
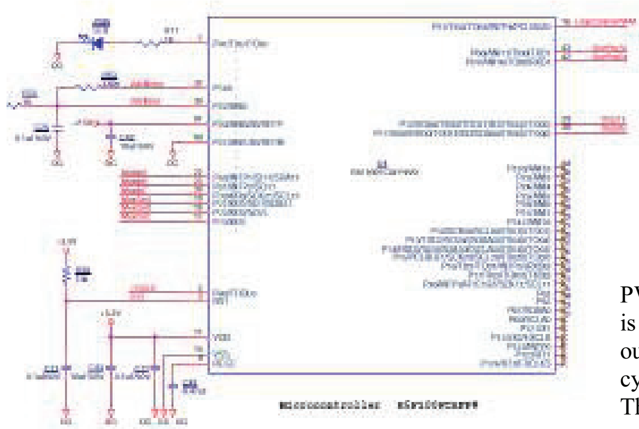


Figure 6 : Secondary side supply

C. Digital circuit design

- The embedded microprocessor R5F100FCAFP whose inner part has a 10 bit ADC[8]
- Ultra-low power technology
- 1.6V to 5.5V operation from a single supply
- 16-bit RL78 CPU core
- 16 KB to 512KB flash memory
- 2KB to 32KB RAM
- High speed on-chip oscillator



•

Figure 7 : Digital Circuit

IV. Current Result and Ongoing Work

This section will feature some of the experimental results that have been achieved. Each of the designs were taken and built in OrCAD Capture CIS 16.6, Multisim for simulation and Cubesuit+ for Programming. Figure 8 shows the results that were achieved from practical implementation. The voltage output of the PWM pin was categorized so that an accurate 2.7V could be applied as the practical limits.

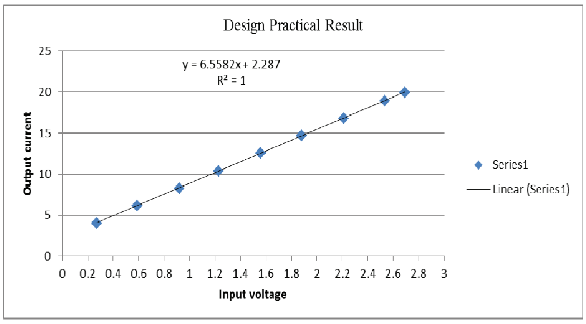


Figure 8 : TT7S Design Practical Results

As can be seen from the practical results in Figure 9 this design was able to achive a current output equal to 20 mA, this design also shows a linear response as the PWM voltage is increased(as the duty cycle of the PWM is increased).

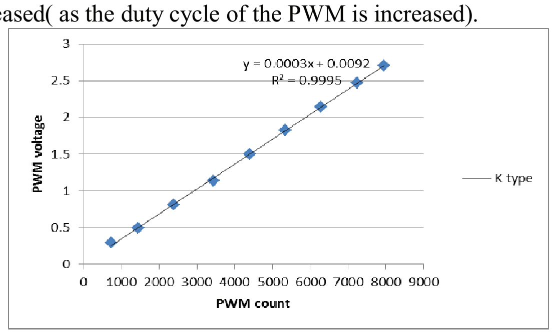


Figure 9 : TT7S PWM voltage vs PWM count

Previously, it was mentioned that a PWM pin will give PWM output and by oversampling method 16 bit PWM count is achieved. It was also mentioned that this different PWM output value was characterized to the number of different duty cycle values. The result of this testing are shown in Table I. The testing was done with the DCO (Digitally controlled oscillator) The PWM values are shown as decimal values and the duty cycle can be calculated as a percentage of the full 16-bit value up to 7950. When plotted, these values give the highly linear plot shown in Figure 9

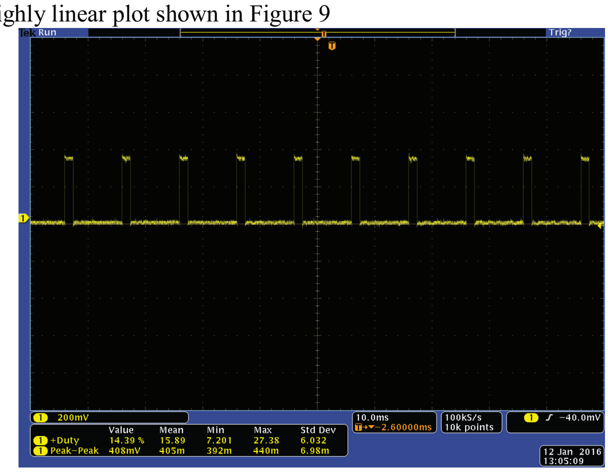


Figure 10 : PWM output measured in DCO

TABLE I. PWM VOLTAGE LEVELS

PWM Val	*1 MHz(V)*
725	0.289
1435	0.489
2383	0.811
3449	1.134
4396	1.498
5344	1.822
6291	2.144
7239	2.468
7950	2.708

From the data accumulated and presented in Figure 9, a corresponding relationship between temperature and output current as would be shown by our particular K type thermocouple sensor. This relationship is shown in Figure 11.

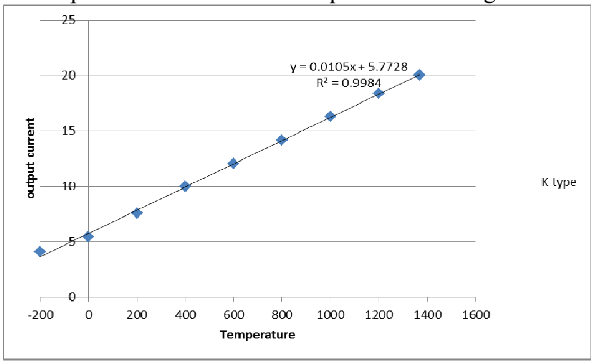


Figure 11 : Practical output Temperature vs Output current

The practical output of the circuit shown on Figure 9 and 11 was then built up and tested with the actual Thermocouple K type sensor. The circuit is tested by the UNICAL device which gives the K type thermocouple input to the temperature transmitter hardware with an accuracy of around 0.1%. The recorded data is shown in Figure 12.

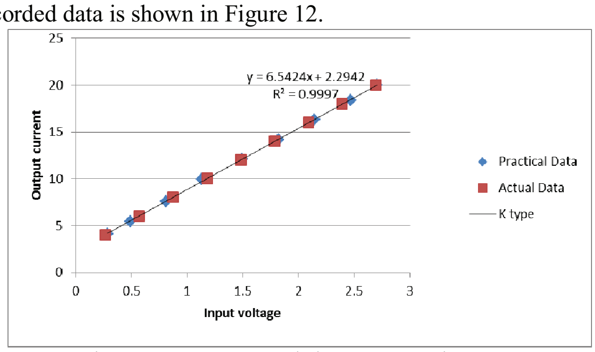


Figure 12 : TT7S Recorded Data Comparison

V. CONCLUSIONS

This paper shows the circuit design of the temperature transmitter. The testing result obtained from the hardware circuit testing. In this paper has reached an accuracy of 0.1%. This circuit design also gives the linearity of the final current loop measurements. For the RTD simulation circuit RTD current source is also achieved which is <1mA. From the results K type sensor output is largely linear. While the experimental results show some non-linearity, this non-linearity allows an opportunity to use software methods to provide a much more linear and accurate response for the transmitter to output by Modbus protocol[9].

ACKNOWLEDGMENT

This work is supported by MASIBUS Automation and Instrumentation Pvt. Ltd. (Gandhinagar) top automation companies in India. And I am thankfull to LJIET and staff members.

REFERENCES

[1] Yuval Hernik-Bar, "How to select precision resistors for 4-20mA current loop", EDN, Internet: http://www.edn.com/design/sensors/44 19750/How-to-select-precision -resistors-for-4-20mA-current-loop , [August, 2013]

[2] Texas Instruments, "RTD Temperature Transmitter for 2-wire, 4-20mA Current Loop Systems," TI Designs Reference Guide - TIDA-00095, Feb. 2014..

[3] Tyler Witt, Rafael Mena, Evan Cornell, "Single chip, 2wire, 4-20mA Current Loop RTD Temperature Transmitter Design," in Industrial Electronics Society, IECON 2014 - 40th Annual Conference of the IEEE Dallas, TX: Oct. 29 2014-Nov. 1 2014, pp. 2380 - 2383.

[4] AVR121: Enhancing ADC resolution by oversampling Application note 2559D-AVR-02/06.

[5] Gang Huang, Jianping Zhang, "Over sampling and used in Temperature Compensation for Acceleration sensor" in ICEMI' 2009, pp. 2-736 to 2-739

[6] Hai sun, Yimin Li, Feng Jiang, "Design and Realization of the intelligent Temperature Transmitter" in International Conference on Mechatronic Science, Electric Engineering and computer, Jilin, china, August 19-22,2011, pp. 388-391

[7] Omega Engineering. "The RTD." Internet: http://www.omega.com/temperature/Z/ TheRTD.html, 2014 [Apr. 10, 2014].

[8] Renesas electronics , microcontroller R5F100FCAFP Datasheet, Nov 15 . 2013

[9] Modicon Modbus Protocol Reference Guide PIMBUS300 Rev.J June 1996.