NON-LINEAR CHARACTERISTIC CORRECTION OF TRANSDUCER USING PROGRAMMABLE FLASH ADC AND REMAPPING

[1]Don Baby, [2]Bijily Rose Varghese

[1]PG Student [Industrial Instrumentation and Control], [2]Asst. Professor
[1]Electrical and Electronics Engineering,
[1]Holy Kings College of Engineering and Technology, Pampakuda, Kerala, India

---

Abstract : Electric transducers/sensors serve as the primary element for communication between an analog physical world and digital electronic world. The transducer analog electrical signals are basically nonlinear in nature. The nonlinear analog electrical signal from the transducer is converted to corresponding digital signal using analog to digital converters (ADCs). ADCs can induce errors in the converted signal. The main error in digitally converted signal may be due to resolution. In this paper a programmable flash ADC is suggested with high resolution. The high resolution programmable flash ADC can convert a nonlinear analog signal to digital signal with less quantization error. The nonlinear analog signal is then linearized using remapping.

***IndexTerms* – Programmable flash ADC, high resolution ADC, nonlinearity correction, remapping.**

I. INTRODUCTION

In automatic controlling and monitoring system the unavoidable integral components are transducers/sensors, ADCs (analog to digital converters) and microcontrollers. Transducers are elements that can convert one form of energy to another form (A.K Sawhney, 2010). Therefore transducers are generally categorized to mechanical and electrical. Electrical transducer converts a physical quantity under measurement to a corresponding electrical signal. Electrical signals from electrical transducers are used by electrical system for further processing and control. Electrical system uses electrical or electronic components for processing, storing and manipulating data. For automatic control and monitoring applications electrical systems are preferred over mechanical systems because of their advantages such as compact size, ease of modification, high efficiency, reliability and quickness.

Most modern process uses microcontrollers or computers for monitoring and controlling applications. Analog signals are not directly accepted by microcontroller or computer, therefore the analog signal must be converted to digital signal. This conversion is done with the help of ADCs. Analog signals from transducers are basically nonlinear in nature. Other factors for the nonlinearity in the transducer output may include offset and gain errors (J.M. Dias Pereira, O. Posstolache and P. Silva Girao 2001). Since resolution of normal ADC are less, nonlinear analog signals when converted to digital signals may contain error or valuable information may be ignored. This error may be due to quantization of sampled discrete analog signals (A. Anand Kumar, 2011). For high resolution ADC the conversion time is high. As the time for conversion increases more valuable data may be ignored. As a solution for this the resolution of the ADC should be increased without compromising for a long conversion time. Therefore a linear signal and high resolution ADC is preferred over nonlinear signal and low resolution ADC. Many methods are used for nonlinearity correction: (i) based on nonlinear analog signal conditional circuits, (ii) based on digital signal processing (DSP) and (iii) based on ADC (J.M. Dias Pereira, O. Posstolache and P. Silva Girao, 2007). Each of this methods have their own advantages and disadvantages. The proposed system is based on DSP and ADC.

A combination of flash, pipeline and multi-step algorithmic ADCs called programmable flash ADC is proposed in this paper which uses less number of comparators compared to other types of ADCs. This digital signal can then be used to linearize the transducer transfer characteristic. A programmable microcontroller is used for transducer characteristic linearization. Remapping is used for linearization of nonlinear characteristic. Linearized signal is preferred because processing, storing, and manipulating variables by a host computer will become simple and easier. Otherwise the host computer should be loaded with many values (set points) and algorithms, for processing inputs from different sensors.

1.1 Flash ADC, Pipeline ADC and Multi-step algorithmic ADC

Flash ADC is considered to be the fastest ADC among other ADCs. For a flash ADC with n bit resolution the number of comparators and resistors needed are $2^n - 1$ and 2^n respectively. Therefore the major disadvantage of flash ADC is that for high resolution, large number of comparators are needed. To be precise an 8 bit flash converter needs 255 (2^8 - 1) comparators and a 10 bit flash converter needs 1023 comparators which will increase the cost for this type of ADC. This problem is overcome using a modified ADC where an 8 bit flash ADC uses two four bit ADC where one 4 bit flash ADC converts the 4 LSB and other 4 bit flash ADC converts the 4 MSB. So it requires only $2\times(2^4 - 1)$ i.e 30 comparators (A. Anand Kumar, 2011).

In pipeline ADC, first stage makes the coarse conversion and next stages helps in fine conversion. Each pipeline stages has its own sample and hold circuit. Therefore a 12 bit converter uses four 3 bit-one 4 bit flash ADCs, time alignment and digital error correction.

Multi-step algorithmic ADC basically contain two stages, its working is almost same as that of pipeline ADC. Two stages has its own sampling, quantizing and residue amplification circuits. The basic difference between pipeline ADC and multi-step algorithmic ADC is that multistep ADC uses the same circuit for different stages, that is, it utilizes same physical space (springer, 2013).

II. Programmable Flash ADC and Remapping

Figure 1 shows the block diagram of the proposed system. The proposed system uses a programmable flash ADC. Programing ability of proposed system makes this ADC suitable for high resolution applications. Programming makes it flexible to achieve different resolution whenever needed at low cost.

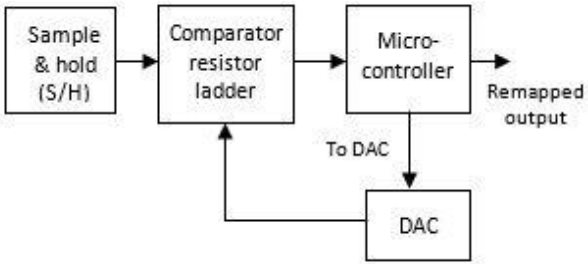

Fig. 1: Block diagram of proposed system

In this system the priority encoder of a normal flash ADC is replaced with a microcontroller. For this ADC, programming ability of microcontroller helps in achieving high resolution. The coarse conversion of the analog signal is done in the first cycle and fine adjustment is done in the successive cycles. The advantage of this ADC over other ADCs are that the comparator required for high resolution digital conversion is less, since same comparator resistor ladder is used for fine and coarse adjustments.

The digital to analog converter (DAC) outputs analog signal corresponding to the bits of each conversion cycle. The analog output from DAC will then serve as analog input voltage and reference voltage for next conversion cycle. The functional block diagram is shown in the figure 2.

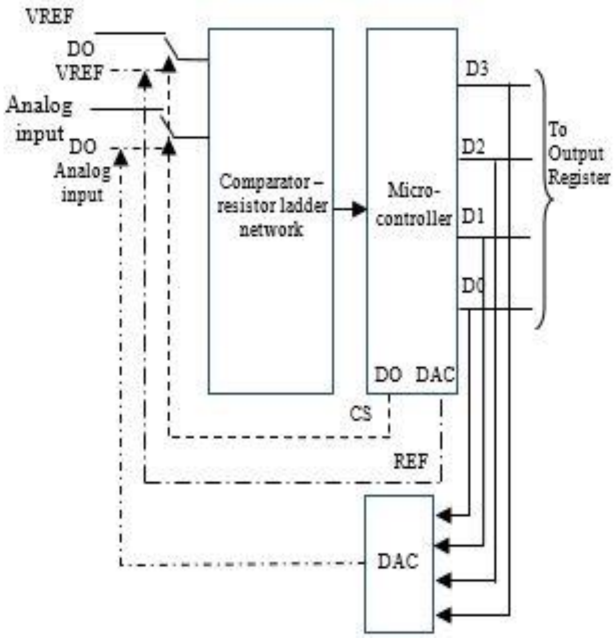

Fig. 2: Functional block diagram of proposed system

In the first cycle an analog input from sensor (input corresponding to measurand) and an external analog input (a reference) are taken respectively. The microcontroller generates a digital signal corresponding to the measured analog signal. The analog value corresponding to the digital signal is subtracted from present analog value. On the completion of first cycle, digital output (DO) pin of microcontroller raises, which is the control signal for switching to DO VREF and DO Analog input respectively. Some microcontroller has inbuilt DAC. This subtracted analog signal and reference value (generated by microcontroller) are then outputted, which is the input for the second cycle. The cycle continue till the required bits have been obtained.

An output register is used to store the digital value of each cycle. After the last cycle, the register holds the digital value corresponding to the analog value under measurement with required bit resolution.

Then linearization is done by remapping. In remapping the voltage from the transducer is remapped to the desired linear characteristic by a microcontroller. This linear analog signal is then used for processing, storing, controlling etc. by the host or remote computers.

A brief description of how remapping is done is shown in the figure 3 (a).

i. Shows a basic nonlinear transducer output characteristic.
ii. Shows a nonlinear transducer characteristic and an ideal (required) transducer characteristic.
iii. Shows a remapped output voltage from a nonlinear sensor output characteristic to a required linear characteristic.

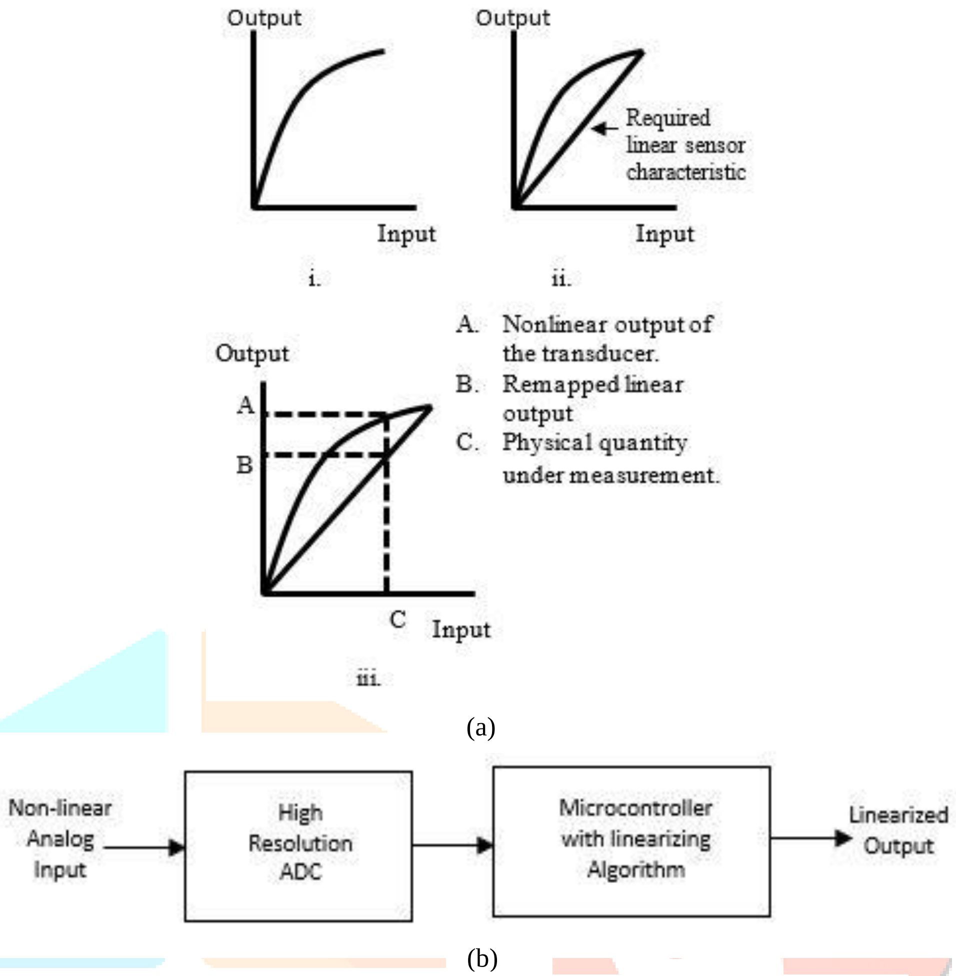

Fig. 3: (a) Description and (b) block diagram of remapping.

The transducer outputs an analog voltage corresponding to the measured value. This analog signal, with nonlinear characteristic, is given to the microcontroller. The analog value is converted to digital using a high resolution programmable flash ADC. The microcontroller then determines the physical quantity under measurement by some relation describing the analog voltage and the measurand, basically a polynomial equation. The microcontroller is provided with an equation for linearizing. The microcontroller then remaps the voltage to the required linear characteristic as per the linearizing equation. Now microcontroller have the linearized value for further processing.

For using remapping to linearize transducer transfer characteristic, ADC used should have high resolution. The advantage of this method is that the nonlinear transducer characteristic remapping can be done in any desired orientation with any required slope. Since remapping is done using microcontroller no additional circuits or components are required. Nonlinearity or errors can be easily rectified to a great extend using remapping. Errors may include offset and gain errors. A problem of using remapping is its difficulty in obtaining an accurate equation for describing the transducer nonlinear characteristic.

III. RESULTS AND DISCUSSION

Transducer used is negative temperature coefficient (NTC) thermistor with 10kΩ (at 25°C). Thermistor is a transducer to measure the temperature. It uses the property of materials that, when temperature varies the resistance get varied. Therefore thermistors can be NTC type or positive temperature coefficient (PTC) type. For PTC thermistors resistance will increase with increase in temperature or vice versa and for NTC thermistors resistance decreases with increase in temperature or vice versa.

Nonlinear characteristic of NTC 10kΩ thermistor is shown in figure 4. Voltage is along y axis and temperature is along x axis. In this results the thermistor is only used for measuring temperature higher than 0°C. Therefore, 1.5 volts can be considered as offset. The main aim is to linearize the nonlinear transfer characteristic of the transducer with minimum offset and gain errors.

The results include analog to digital (A/D) conversion using proposed ADC with different resolutions and linearization using remapping.

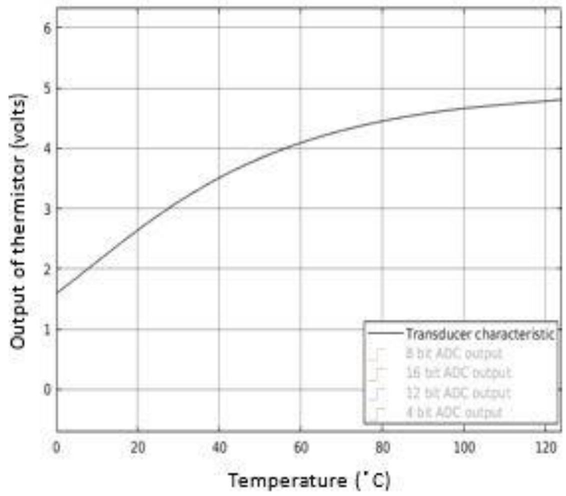

Fig. 4: Nonlinear transducer characteristic

The results with different resolutions: 4 bit, 8 bit, 12 bit and 16 bit are shown in figures 5, 6, 7 and 8 respectively. Figure 5 clearly shows the missing or ignoring of input between 3.5 V and full scale value (FSV) by a low resolution ADC (4 bit ADC). This missing of bit will result in error which will be transferred to the succeeding stages of processing. The error in the output of ADC is mainly due to nonlinearity and inherit error of transducer such as offset and gain error.

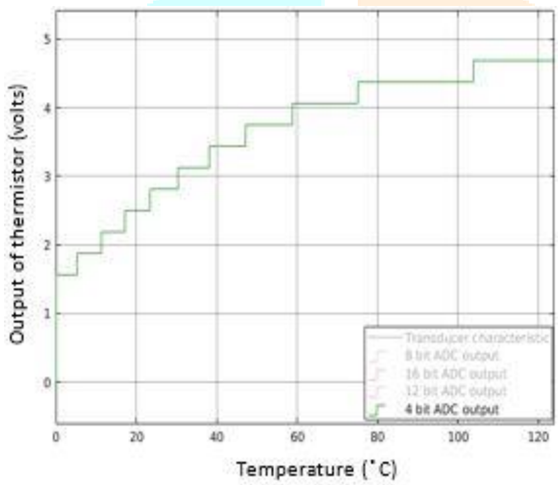

Fig. 5: Output of 4 bit ADC for nonlinear transducer characteristic

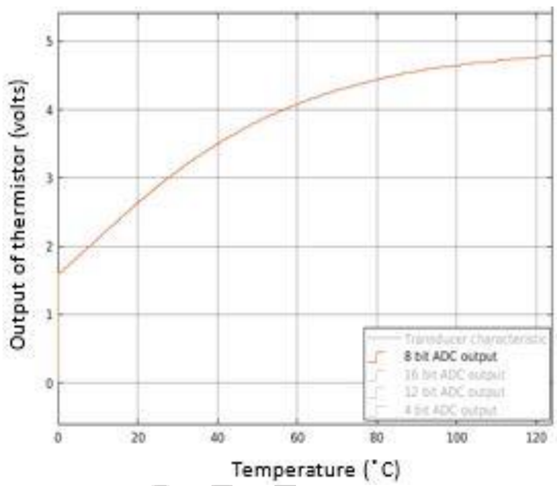

Fig. 6: Output of 8 bit ADC for nonlinear transducer characteristic

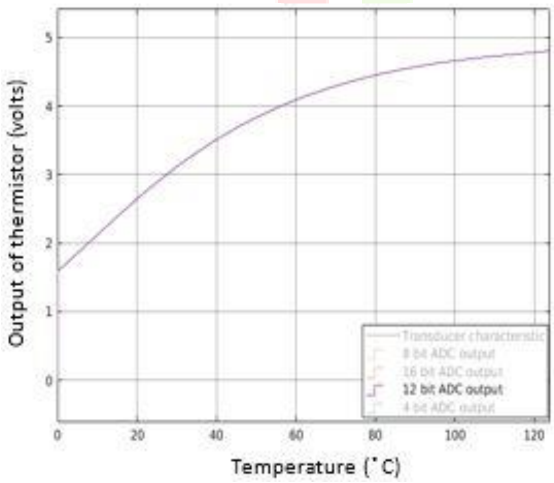

Fig. 7: Output of 12 bit ADC for nonlinear transducer characteristic

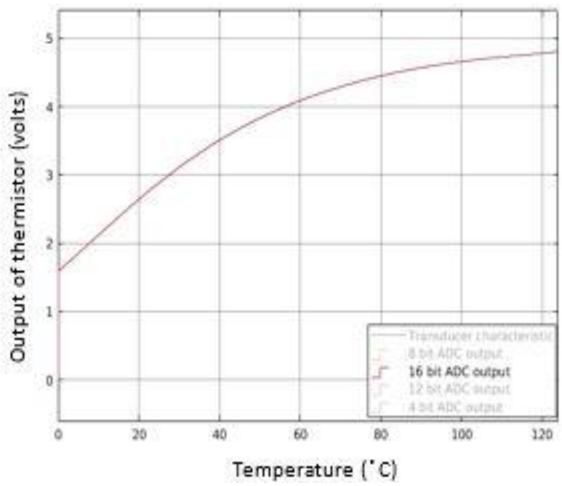

Fig. 8: Output of 16 bit ADC for nonlinear transducer characteristic

Result of 8 bit ADC doesn't show any large error as 4 bit ADC. But errors are present at FSV. In the figures 6, 7 and 8 curve seems to be a fine continuous line, but actually they are steps with small size. Results of 12 bit ADC and 16 bit ADC does not show any distinguishing differences. Therefore results of 16 bit ADC is neglected for simplification.

Figure 9 shows ideal linear characteristic of the thermistor. Output of each ADC is linearized using remapping. Linearized results of each ADC are shown below. Figures 10, 11 and 12 shows linearized result of 4 bit, 8 bit and 12 bit ADCs respectively.

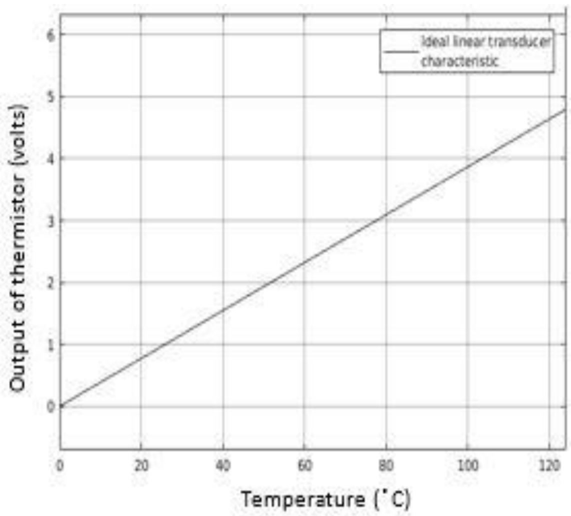

Fig. 9: Ideal linear output of the thermistor

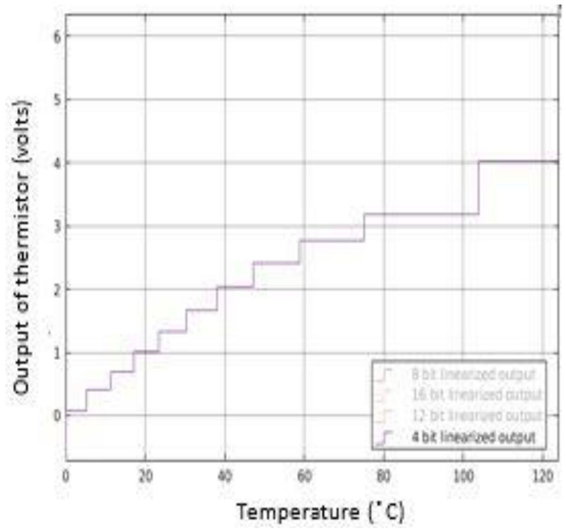

Fig. 10: Linearized output for a 4 bit digital input

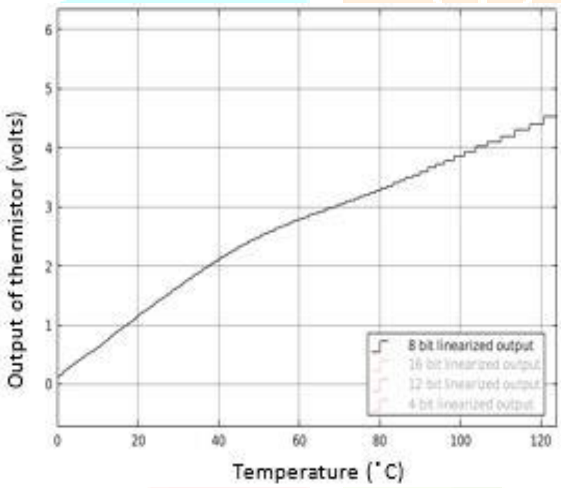

Fig. 11: Linearized output for an 8 bit digital input

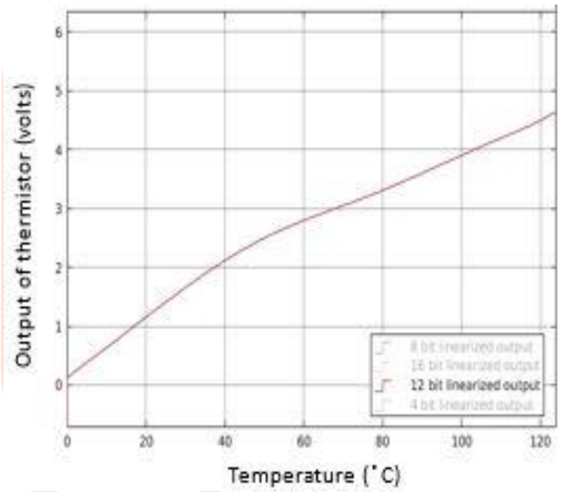

Fig. 12: Linearized output for a 12 bit digital input

It is clear that nonlinearity (error) is still present in the linearized output with a 4 bit digital input. This nonlinearity is due to the poor resolution of ADC used in the preceding stage. This problem is reduced by using ADC of high resolution. For an 8 bit digital input the remapped signal is almost linear but the resolution reduces as FSV is approaching. Result in figure 12 shows an almost linear transfer characteristic and the problem of decreasing resolution near the FSV have been overcome, since it uses a 12 bit ADC in the preceding stage. The noticeable achievement for a remapped signal is that the offset of the normal transducer characteristic have been minimized to an acceptable limit without any external circuits.

Error between remapped linearized output and a normal linear output is shown in the figures 13, 14 and 15. From these figures it is clear that the error is minimized as the resolution of the ADC increases. Error means the difference between remapped output and an ideal transfer characteristic. Therefore this error can be reduced by linearizing the remapped output to an ideal linear characteristic. This is practically very difficult to achieve.

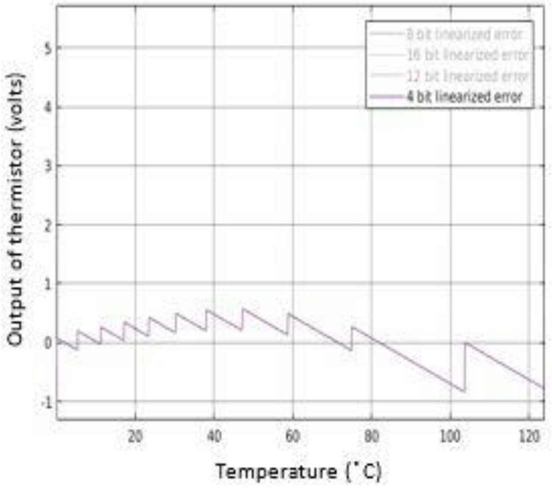

Fig. 13: Error between linearized 4 bit digital signal and ideal linear characteristic

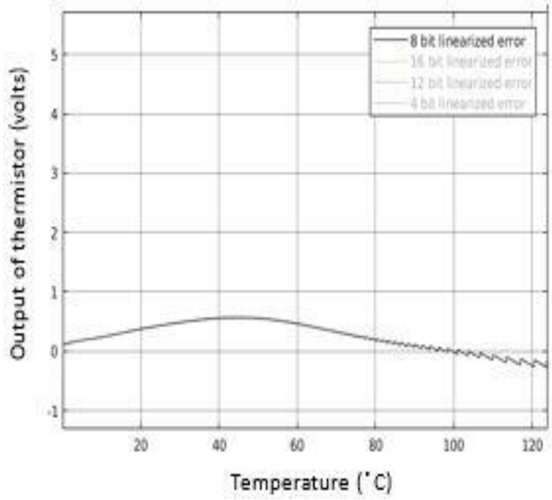

Fig. 14: Error between linearized 8 bit digital signal and ideal linear characteristic

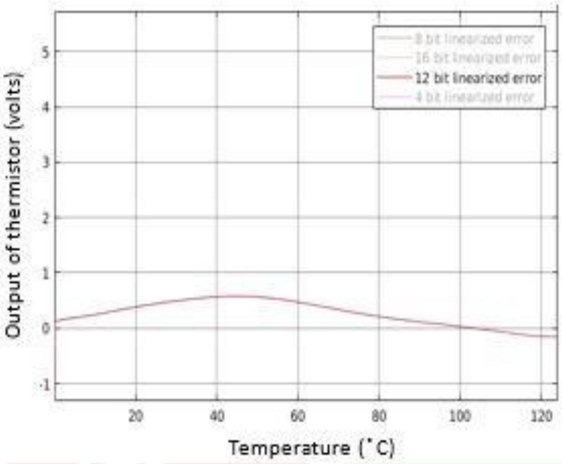

Fig. 15: Error between linearized 12 bit digital signal and ideal linear characteristic

IV. Conclusion and Future Scope

The proposed system converts an analog signal from 10kΩ thermistor to digital signal of high resolution without compromising much on conversion time and the error of the linearized signal using remapping is considerably low. Error in the remapped signal can be reduced much more by careful designing.

Any transducer output or any signal nonlinearity can be linearized using the proposed method.

References

[1] D. Patranabis, S. Ghosh and C.Bakshi, 1988, Linearizing transducer characterististics, IEEE transactions on instrumentation and measurement, vol. 37, no. 1.

[2] J.M. Dias Pereira, O. Posstolache and P. Silva Girao, 2001, PWM- A/D Conversion: A Flexible and low cost solution for transducer linearization, sicon'01 sensors for industry conference Rosemount, Illinois, USA.

[3] J.M. Dias Pereira, O. Posstolache and P. Silva Girao, 2007, A digitally programmable A/D converter for smart sensors application, IEEE truncations on instrumentation and measurement, vol. 56, no. 1.

[4] Guillermo Enrique Iglesias and Enrique Alberto Iglesias, 1988, Linearization of transducer signals using an Analog-to-Digital Converter, IEEE truncations on instrumentation and measurement, vol. 37, no. 1.

[5] Giovanni Bucci, Marco faccio and Carmine Landi, 1997, The implementation of a smart sensor based on a piece-linear A/D converter, IEEE instrumentation and measurement Technology Conference, Ottawa, Canada.

[6] http://www.maximintegrated.com/en/app-notes/index.mvp/id/1023.

[7] A. Anand Kumar, 2011, Fundamentals of digital circuits, PHI Learning private Limited.

[8] D. Patranabis, 2013, sensors and transducers, PHI Learning Private Limited.

[9] https://www.springer.com/cda/content/document/cda_downloaddocument/9781461434665-c2.pdf?SGWID=0-0-45-1348414-p174308086, 2013.

[10] A.K Sawhney, 2010, A course in electrical and electronics measurements and instrumentation, Dhanpat Rai & CO. (P) LTD.