

## ON LINEARISATION OF THERMOCOUPLE SIGNALS USING ANALOG – TO – DIGITAL CONVERTER

**A.Abudhahir\* and V.Subbiah Bharathi**

Department of Electronics and Instrumentation Engineering,

**V.Srinivisa Raghavan**

Department of Electrical and Electronics Engineering,

National Engineering College, Kovilpatti – 628 503.

Tuticorin District, Tamilnadu, India.

**S.Munshi**

Department of Electrical Engineering,

Jadavpur University, Kolkata – 700 032.

West Bengal, India.

**Abstract** A novel circuit for linearisation of thermocouple signals using Analog – to – Digital converter (ADC) is proposed. The present method utilises the ratiometric property of ADCs and the converter performs analog to digital conversion as well as linearisation. The resulting circuit also has provision for scaling the linearised digital output to obtain a desired full-scale value. Computational studies carried out on method proposed gives satisfactory results for thermocouples with monotonic concave upward and downward characteristics.

*Keywords: Thermocouple, Linearisation, Analog – to – Digital Converter, Scaling.*

### INTRODUCTION

Most of the transducer characteristics are almost nonlinear in nature. Like all other transducers, thermocouples also do not have perfectly linear relations. Even for thermocouples with decent linearity the nonlinearity is not too small to ignore. It is therefore imperative that linearisation techniques be also employed for thermocouple based temperature measurement systems.

The generalized software based linearisation techniques for transducers [Ghosh and Patranabis, 1991] [Patranabis and Ghosh, 1988] can also be used for the thermocouples. However in literatures, the results of application of these methods to thermoelectric transducers have seldom been reported. So far as hardware based methods are concerned, in research publications one rarely comes across linearising circuits developed for thermocouples.

In the present work, a relatively inexpensive hardware method for linearisation of thermocouple signals using ratiometric property of ADC has been proposed. The present method using ADC is an improvement on the basis method proposed earlier [Iglesias and Iglesias], in the sense that the modified scheme uses independent linearisation and scaling arrangements.

### THEORY OF THE PROPOSED CIRCUIT

The digital count output  $L$  of dual-slope integration type A/D converter with differential input is given by

$$L = \frac{C (V_{IN}^+ - V_{IN}^-)}{V_{Ref}} \quad (1)$$

where  $V_{IN}^+$  and  $V_{IN}^-$  are the analog input voltages,  $V_{Ref}$  is an analog reference voltage, and  $C$  is the digital count output when  $(V_{IN}^+ - V_{IN}^-) = V_{Ref}$ .

If  $V_{IN}^+$  is the voltage signal  $E(x)$  from a transducer circuit ( $x$  being measurand), following an approach proposed by Iglesias et al., a quasi – linear relation between  $L(x)$  and  $x$  can be achieved by suitably modifying the equation (1) such that,

$$L(x) = \frac{C(1+K)E(x)/E_r}{1+K E(x)/E_r} \quad (2)$$

Where the analog reference voltage is

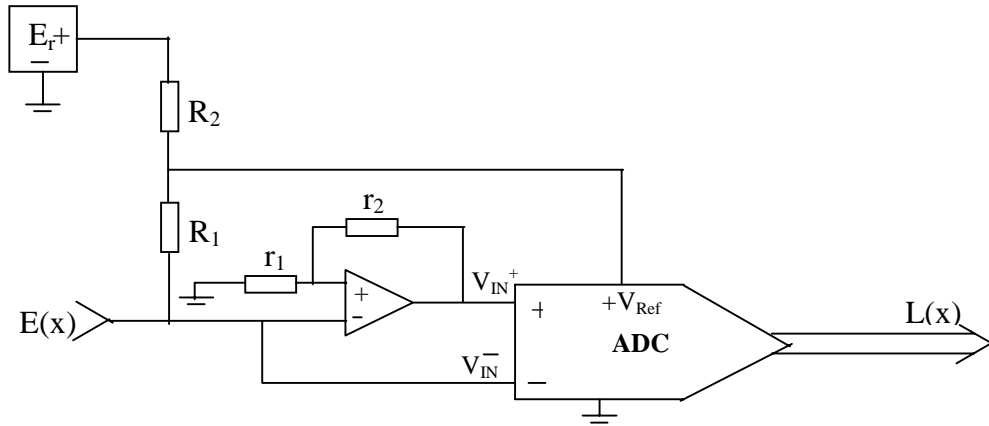
$$V_{Ref}(x) = \frac{E_r + K E(x)}{1+K} \quad \text{for positive } K,$$

$$V_{Ref}(x) = E_r + K E(x) \quad \text{for negative } K,$$

$K$  is the linearising coefficient, whose optimum value is to be determined.

---

\*Email: ameerbasha\_a@yahoo.com



**Fig.1 Block Diagram of Proposed Linearising Circuit for Positive ‘K’**

For the two cases, the expressions for the linearising coefficient in terms of circuit resistances are  $K=R_2/ R_1$  and  $K = - R_2 / (R_1+R_2)$  respectively.

In our case,  $x$  is the temperature  $T$  under measurement and  $E(x)$  is  $E(T)$  - the thermoemf from the thermocouple after appropriate reference junction compensation.

Suppose it is desired that at the full-scale value of  $x_f$  of the measurand, the digital output should be  $L(x_f)=AC$ . Where the maximum possible value of  $A$  depends on the ADC under consideration.

As an example, for INTERSIL ICL 7135 ADC, the maximum allowable value of  $A$  is 2. Then,

$$E_r = \frac{E(x_f)}{A} [1+K(1-A)] \quad (3)$$

The constant  $A$  represents the sensitivity of the arrangement.

Over a certain span of temperature, based on a desired value of  $A$ , an optimum value of  $K$  can be obtained.  $E_r$  can be adjusted to achieve the desired value of  $A$ . For the same span of temperature, if it is required to have an increased sensitivity  $A$  by changing  $E_r$ , the linearity will be disturbed. Hence this method of achieving a desired full-scale digital output has not been considered.

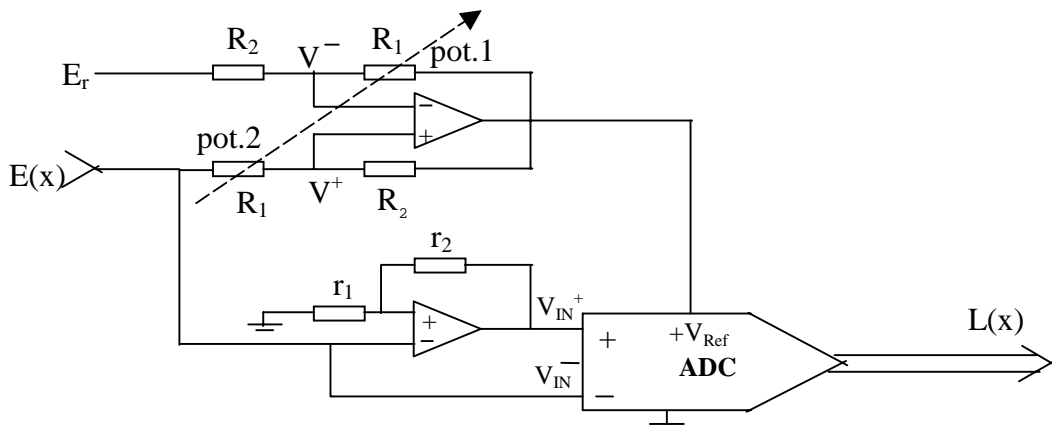
As an alternate approach, the linearising arrangement is so designed that the scaling and linearising mechanisms are independent of each other. Then the digital output count is given by,

$$L(x) = \frac{CA(1+K)E(x)/E_r}{1+KE(x)/E_r} \quad (4)$$

where  $A$  is the scaling constant. If  $E_r$  is adjusted to  $E(x_f)$ , the full-scale digital output is  $L(x_f) = AC$ . Then,

$$L(x) = \frac{CA(1+K)E(x)/E(x_f)}{1+KE(x)/E(x_f)} \quad (5)$$

The block diagram representations of relevant circuits are given in Fig.1 (for positive  $K$ ) and Fig.2 (for negative  $K$ ).



**Fig.2 Block Diagram of Proposed Linearising Circuit for Negative ‘K’**

The normalised deviation of  $L(x)$  vs  $x$  characteristic from linearity for any value of  $x$  is,

$$D(K, x) = \frac{L(K, x)}{L(K, x_f)} - \frac{x}{x_f} \quad (6)$$

The optimum value of  $K$ , is obtained by numerically minimizing  $D^2(K, x)$  as a function  $K$ . The sum-squared deviation is given by

$$S = \sum_{n=1}^N D^2(K, x_n) \quad (7)$$

where  $N$  denotes the number of  $x$  values considered for computation. An approximate value of  $K=K^*$  is obtained by imposing the condition,

$$L(x_f) = 2L(x_f/2) \quad (8)$$

The optimum value of  $K$  is then obtained by varying  $K$  in steps about the value  $K^*$  and computing  $S$  for each value of  $K$  by varying  $x$  in steps from 0 to  $x_f$ . Value of  $K$  for which  $S$  is minimum, is chosen as the optimum one. The optimum value of  $K$  will attain positive sign for concave upward signals (negative nonlinearity) and negative for concave downward signals (positive nonlinearity).

### CIRCUIT ANALYSIS

#### For Positive $K$

In the circuit shown in Fig.1,

$$V_{IN}^+ = [1 + (r_2/r_1)] E(x) \quad (9)$$

$$V_{IN}^- = E(x) \quad (10)$$

$$V_{Ref}(x) = \frac{E_r}{1+K} + \frac{K}{1+K} E(x) \quad (11)$$

where,  $K = (R_2/R_1)$  is the linearising coefficient. The digital output of the ADC is as given in equation 4. Where,  $A = (r_2/r_1)$  is the scaling constant.

#### For Negative $K$

In the circuit shown in Fig.2,

$$V^+ = \frac{R_2}{R_1+R_2} V_{Ref}(x) + \frac{R_1}{R_1+R_2} E_r \quad (12)$$

$$V^- = \frac{R_1}{R_1+R_2} V_{Ref}(x) + \frac{R_2}{R_1+R_2} E(x) \quad (13)$$

Since  $V^+$  should be equal to  $V^-$ ,

$$V_{Ref}(x) = \frac{E_r}{1+K} + \frac{K E(x)}{1+K} \quad (14)$$

where,  $K = (-R_2/R_1)$  is the linearising coefficient. Again,  $V_{IN}^+ = (1 + r_2/r_1) E(x)$  and,  $V_{IN}^- = E(x)$ . The digital count output  $L(x)$  is as expressed in equation (4). It is quite obvious that pot.1 and pot.2 are ganged. It should also be ensured that  $R_2$  is always less than  $R_1$ .

It is to be noted that if  $E(x)$  is zero when  $x$  is zero, for both the circuits shown in Fig.1 and Fig.2,  $L(0)$  is zero.

In both cases, full-scale calibration can be carried out as follows:

- (i) Setting the measurand  $x = x_f$ , and  $A=1$ ,  $E_r$  is adjusted to make  $L(x_f) = C$ . This can be achieved with  $E_r = E(x_f)$ .
- (ii) Then  $A$  can be adjusted to obtain the desired value of full scale ADC output  $L(x_f) = AC$ .

For both schemes, with  $x = x_f$ , the reference voltage of the ADC is  $V_{Ref}(x_f) = E(x_f)$ . After the full-scale calibration is carried out, the linearising coefficient  $K$  should be adjusted to its optimum value obtained by an appropriate method.

### RESULTS AND DISCUSSIONS

In order to assess the performance of the proposed circuits, computational studies have been carried out using the manufacturer's data for Copper-Constantan (T-type) and Iron-Constantan (J-type) thermocouples [Dhal,1962], considering different temperature ranges for each type. The specifications of a dual slope INTERSIL ICL 7135A/D converter in its standard configuration, having a full-scale voltage of 2V and  $C=10000$ , have been considered in this study. Scaling constant ( $A$ ), reference voltage ( $E_r$ ) and optimum value of linearising coefficient ( $K$ ) have been determined for T-type (0 °C -300 °C and 0 °C - 400 °C) and J-type (0 °C -300 °C and 0 °C -760 °C). These values are tabulated in Table 1.

The plots of %deviation from linearity as a function of temperature, before and after linearisation, are given in Fig.3 for T-type thermocouple over the temperature range 0 °C -300 °C. It is clearly seen from the plot that the magnitude of maximum deviation before and after linearisation is 4.917% (equivalent to 14.751 °C) and 0.447% (equivalent to 1.341 °C). Likewise, in Fig.4, for the temperature range 0 °C -400 °C, after linearisation, the magnitude of maximum deviation is 0.623% (equivalent to 1.869 °C) and its value is 5.540% (equivalent to 22.16 °C) before linearisation.

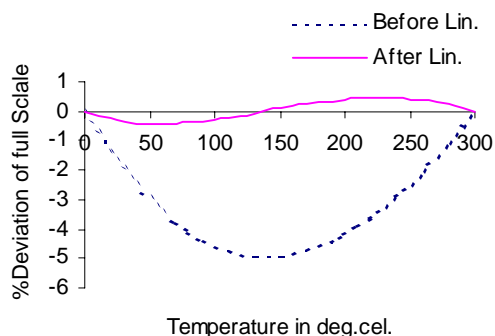
Fig.5 and Fig.6 depict the %deviation vs. temperature characteristics for J-type thermocouple over the temperature ranges 0 °C -300 °C and 0 °C -760 °C respectively. It is clearly observed from the plots in Fig.5 that the magnitude of maximum deviation is 1.065% (equivalent to 3.195 °C) before linearisation and its value is 0.276% (equivalent to 0.828 °C) after linearisation. Fig.6 portrays the way in which the %deviation of  $L(x)$  vs.  $x$  response from the linearity varies with the temperature. The observed magnitude of maximum deviations before and after linearisation are 1.998% (equivalent to 15.183 °C) and 0.447% (equivalent to 3.625 °C) respectively.

**INFERENCES**

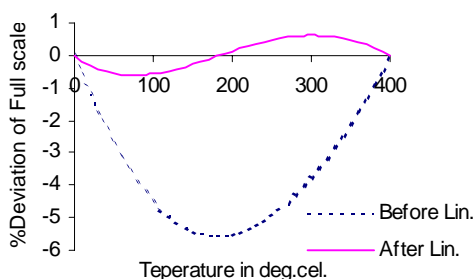
The proposed technique works extremely well for T-type thermocouple. In the range 0 °C to 300 °C, the

**Table 1: Optimum value of K for T and J type thermocouple**

Type	Temp. Range °C	K	A	Er mV
T	0-300	0.222	0.03	14.860
	0-400	0.254	0.04	20.869
J	0-300	0.042	0.03	16.325
	0-760	0.083	0.076	42.922

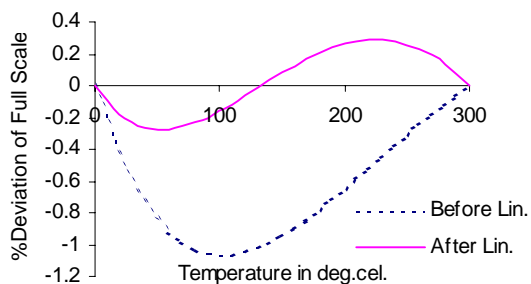


**Fig.3. Percent deviation of full scale as a function of temperature for T-type thermocouple over the range 0 to 300°C**

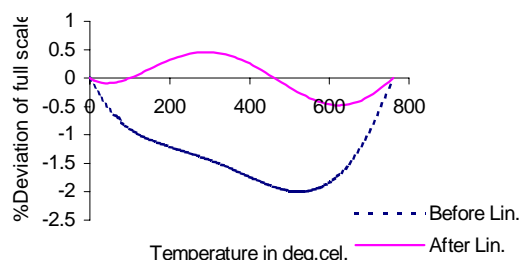


**Fig.4. Percent deviation of full scale as a function of temperature for T-type thermocouple over the range 0 to 400°C**

the deviation from linearity is within  $\pm 0.447\%$  which is comparable with the maximum nonlinearities of 0.36% and 0.63% obtained with Bolk's algorithm and Lagrange interpolation respectively [Bolk,1985]. Even the value over 0 °C to 400 °C is of same order as the values obtained with the Bolk's algorithm for a lower range of 0°C to 300 °C. For the J-type thermocouple the proposed circuit performs commendably. When used in the range 0°C to 300°C, the nonlinearity is within  $\pm 0.29\%$ , while for the same range the maximum nonlinearity obtained by both Lagrange interpolation and Bolk's algorithm is  $\pm 0.23\%$  [Bolk,1985]. The results for 0°C to 760°C are also good, the maximum nonlinearity in this range being  $\pm 0.48\%$  of full scale.



**Fig.5. Percent deviation of full scale as a function of temperature for J-type thermocouple over the range 0 to 300°C**



**Fig.6. Percent deviation of full scale as a function of temperature for J-type thermocouple over the range 0 to 760°C**

**CONCLUSION**

A simple hardware method to correct the thermocouple nonlinearity has been described. Numerical studies revealed that excellent results could be obtained if the proposed circuit is used for linearising signals from T and J type thermocouples. The results are comparable to those obtained by other investigators using software techniques. Thus, these thermocouples, together with appropriate inexpensive cold junction compensation arrangement and this linearising circuit, can be expected to constitute a self-sufficient temperature measuring system with digital output.

**REFERENCES**

Bolk, W.T., "A General Digital Linearising Method for Transducers", *J.Phys.E.Sci.Instrum.*, **18**, pp.61-64, (1985).  
 Dahl, A.I, "Temperature, Its Measurement and Control in Science and Industry", Reinhold Publishing Corporation, Chapman & Hall Ltd., London (1962).  
 Ghosh, D. and Patranabis, D., "Linearisation of Transducers Through a Generalised Software Technique", *J.Phys.E:Meas.Sci.Technol.*, **2**,pp.102-105 (1991).  
 Iglesias, G.E and Iglesias ,E.A., "Linearisation of Transducer Signals Using Analog - to - Digital Converter", *IEEE Trans.Instrum.Meas.*, **37**, pp.53-57 (1988).  
 Patranabis, D. and Ghosh, D., "A Novel Software-Based Transducer Lineariser", *IEEE Trans. On Instrumentation and Measurement*, **38**, pp.1122-1126 (1989).  
 INTERSIL Data Manual.