Development of Thermistor Linearization Circuit based on Modified 555 Timer using LabVIEW

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Abstract:
Thermistors have high sensitivity which makes them suitable for various applications, but they exhibit a highly nonlinear resistance-temperature relationship which is exponential in nature. This nonlinearity is an important problem and a lot of research has been dedicated to correct it. In this paper a virtual instrument has been developed based on the modified 555 timer circuit using LabVIEW to obtain a linearized characteristic. The possibility of developing the proposed instrument as a temperature sensor with frequency as output has been investigated through simulation. It has been shown that the linearization of the thermistor characteristic is achieved by selecting the suitable parameters of the thermistor, the frequency determining elements and the control voltage of modified 555 timer circuit without connecting any additional elements. The experimentally obtained characteristics have a good match with the theoretically obtained characteristics through the investigations conducted in this paper. In a specific range of temperature the proposed circuit is characterized by high temperature stability, improved sensitivity and nonlinearity of about ±1% .

Keywords: Thermistor, Linearization, Modified 555, LabVIEW, Temperature Sensor, Data Acquisition.

1. Introduction

Negative temperature coefficient (NTC) thermistors are temperature sensors whose resistance decreases with increase in temperature. They are used for precise measurement of temperature in various fields like food, automobile, chemical industries and in medicine because of their high sensitivity, low cost and convenient physical shape. The NTC thermistors are composed of metal oxides. The most commonly used oxides are those of manganese, nickel, cobalt, iron, copper and titanium [1]-[3]. The fabrication of commercial NTC thermistors uses basic ceramics technology and continues today much as it has for decades. In the basic process, a mixture of two or more metal oxide powders are combined with suitable binders, are formed to a desired geometry, dried, and sintered at an elevated temperature. By varying the types of oxides used, their relative proportions, the sintering atmosphere, and the sintering temperature, a wide range of resistivity and temperature coefficient characteristics can be obtained.

Thermistors when used for temperature measurements, they are connected in circuits like voltage divider or bridge circuits. However, because of nonlinearity different methods are used to linearize the characteristic of thermistor [2], [3]. One of the methods is to connect passive element either in parallel or series to make the characteristic linear [4], [5]. The second method is to connect thermistors in circuits with logarithmic amplifiers [6]-[8]. The third method is to convert temperature to frequency where active elements are used [9]-[13]. Apart from these methods, computer methods for linearization are also used where lookup tables are used [14] ,[15].

National instruments developed Laboratory Virtual Instrument Engineering Workbench (LabVIEW). It is a graphical programming language used in a variety of industries for measurement, control, data analysis, data presentation [16], [17]. LabVIEW provides icons to manage and represent the user interface; it helps to develop a human-friendly front panel which can be customized according to our requirements for the analysis and design. In this paper LabVIEW is used for simulating the thermistor linearization circuit. LabVIEW is also used for real time data acquisition where the thermistor is interfaced with LabVIEW through a NI cDAQ 9174 card. A real time voltage value is acquired and is converted into resistance and temperature and this data is used in the simulation to get the linearized characteristic. Fig.1 shows the thermistor output acquisition system.

In this paper a virtual instrument has been proposed in which, the thermistor measures the temperature of a water bath and the measured value is interfaced with LabVIEW. This virtual instrument is designed with the help of LabVIEW .The thermistor circuit consists of a modified version of 555 timer which is used to linearize the characteristic of the thermistor. Utilizing the frequency determining parameters of circuit, thermistor parameters and the controlled voltage under a pre specified working temperature range, the thermistor characteristic has been linearized. A wider linearization range is obtained when thermistors with lower B values are used, such as V_2O_5 based thermistors. As we obtain frequency as the output, the signal has higher noise immunity.

2. Theoretical Background

For an NTC thermistor, the temperature dependence of the resistance R_T is exponential, as shown in Eq. (1)

$$R_T=R_0 \exp [B (1/T-1/T_0)] \qquad (1)$$

Where R_0 is the zero-power resistance at a specific temperature T_0 in Kelvin, and B is the characteristic temperature of the material. B is the material constant (expressed in kelvins), which is determined by the activation energy q and he

Boltzmann's constant k with the dependence B = q/k [18]. The thermistor connection circuit uses the modified 555 timer circuit [19]. The proposed circuit of 555 timer is built on the laboratory using discrete electronic components. Fig. 2 shows the schematic of the circuit with the components that were used during the experiment. By controlling the input signal (Vcon), the output switching frequency (fs) is adjusted; an expression that describes the relationship between Vcon and fs is given by Eq. (2), where R_T is the thermistor and R_a and C_T are the frequency determining elements.

$$f_s = f(T) = \frac{1}{\ln\left|\frac{V_{cc}}{V_{con}} - 1\right|(C_T(2R_T + R_a))} \qquad (2)$$

$$f_s = f(T) = \frac{1}{\ln\left|\frac{V_{cc}}{V_{con}} - 1\right|(C_T(2R_{T25}e^{B(\frac{1}{T}-\frac{1}{298})} + R_a))} \qquad (3)$$

Where, R_{T25} is the resistance of the thermistor at 25°C, which together with B is given in the reference data of the thermistor of the manufacturer.

The graph of the transformation function given in Eq.3 and their first and second derivatives with respect to temperature T f' (T) and f'' (T) are shown in Fig.3.

The above transformation function (3) contains an inflection point which is the extreme point of the first derivative and the corresponding value in the second derivative is zero. Around the inflection point, the changes for the first derivative are least and the characteristic of the measure can be treated as linearized in this range.

3. Experimental Results

NTC thermistors with different parameters have been selected to conduct the investigations. The V2O5-based thermistor has been used in the investigation and it has prepared using classical ceramic technology [20] in which the ceramic samples have been synthesized at a temperature of 660°C for 2 hrs. After being fired, the ceramic samples have been ground and cleaned in an ultrasonic basin. They have been coated with Leitsilber 200 (a silver solution in ethylene glycol and xylol) to form electrodes. The experimentally investigated thermistors [18], [19] are shown in Table 1.

3.1 Simulation of the proposed circuit characteristic for the thermistor linearization

For the simulation, LabVIEW software package has been used. The proposed circuit has been simulated with the virtual process having the temperature variation from 0°C to 120°C and the corresponding front panel diagram is as shown in Fig.4. A simulation of the proposed circuit characteristic is conducted for thermistors with the parameters given in Table 1 at Rτ= 1000Ω , Cτ=120 nF and Vcon=2V. The simulated results are shown in fig.5. According to the simulation results, the linearity in the widest range is observed for therm 1 (0°C to 120°C) which has the lowest value of B. The linearized segment for therm 2 is between 30°C to 120°C whereas for therm 3 it is above 90°C. To achieve linearized characteristic for therm 3, higher value of Rτ is used. The simulation result for all the thermistors when Rτ=6000Ω and Cτ=50nF is shown in fig.6. the characteristic shows linearization for therm 3 in the range around 40°C to 120°C.

3.2 Experimental investigation

The investigation of the temperature dependences is carried out using a water bath in the range from 0°C to 120°C. The experiment is carried out with the proposed circuit and thermistors with the parameters used same as simulations. The temperature is measured using a mercurial thermometer with precision of up to 0.5°and the resistance has been measured with the 4 digit TX3 true digital multimeter.

The output frequency and voltage of the proposed circuit insignificantly change with the change in temperature. The error from the temperature influence on the frequency output circuit for the thermistors is significantly small.

4. Conclusion

As a result of the investigations and the simulations conducted in this paper, the possibility of developing the virtual instrument as a temperature sensor based on the modified 555 with frequency as output and a linearized characteristic has been shown. The linearization of the transformation function is achieved without connecting additional elements to the circuit, but rather through a selection of a thermistor and the parameters of the frequency-determining circuit elements and the controlled voltage.

Following conclusions can be made on the basis of the obtained results.

1) A selection of a thermistor with a lower value of B leads to a wider linearized segment of the thermistor characteristic.

2) A specific frequency range of the output signal of the Thermistor can be selected through a change in the value of the frequency-determining capacitance Cτ of the timer, given the pre specified selected parameters of the thermistor and the frequency-determining resistance Rτ.

3) The sensitivity of the proposed instrument can be improved with the selection of control voltage preferably ranging from 0.5V to 2V.

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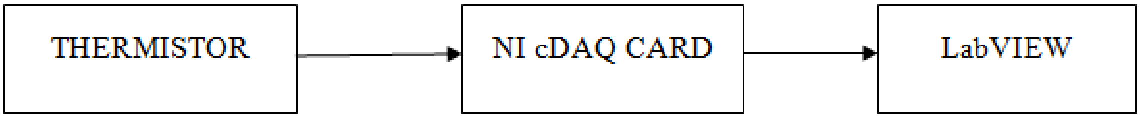


Fig.1. Thermistor data acquisition system

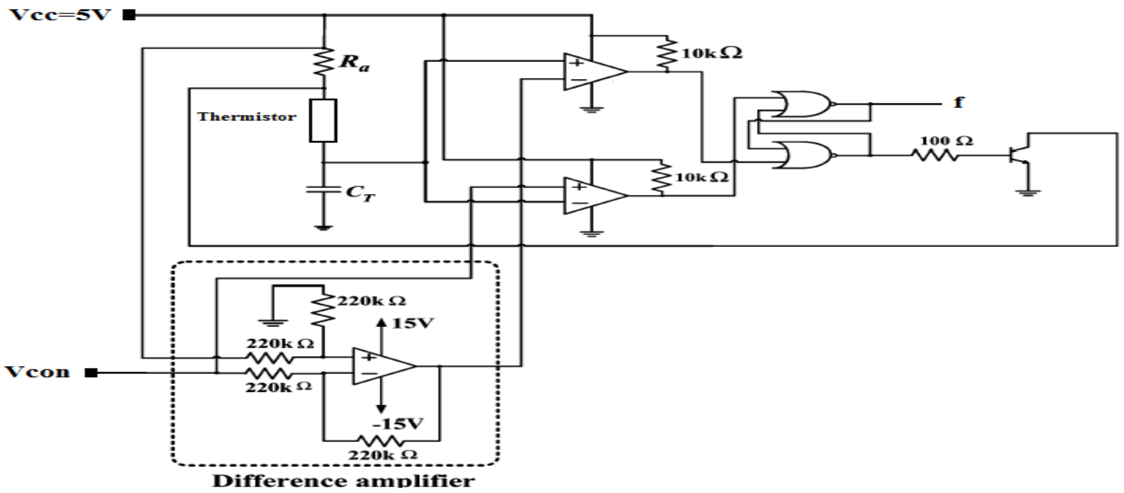
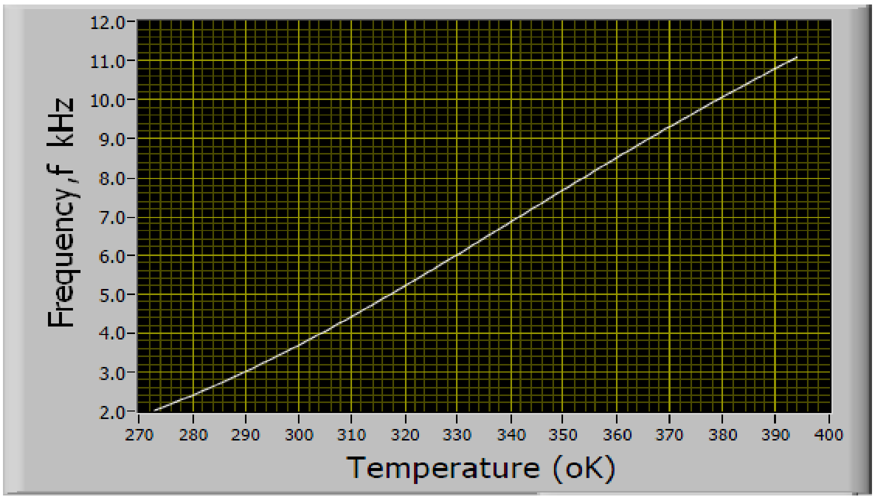
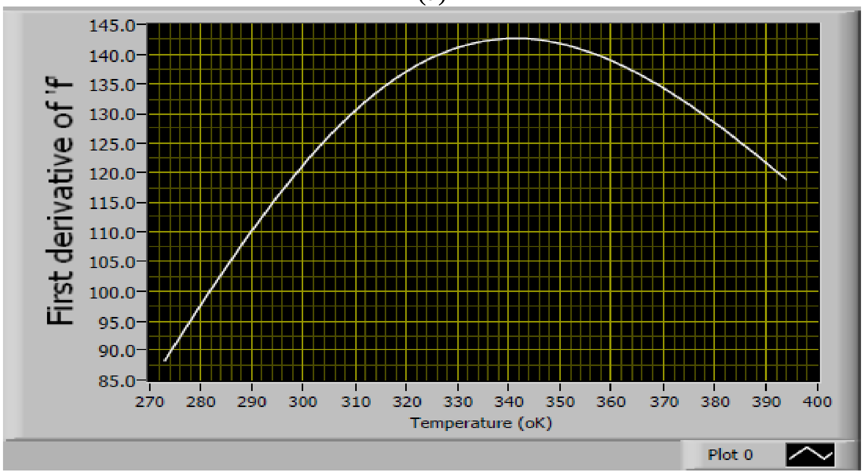


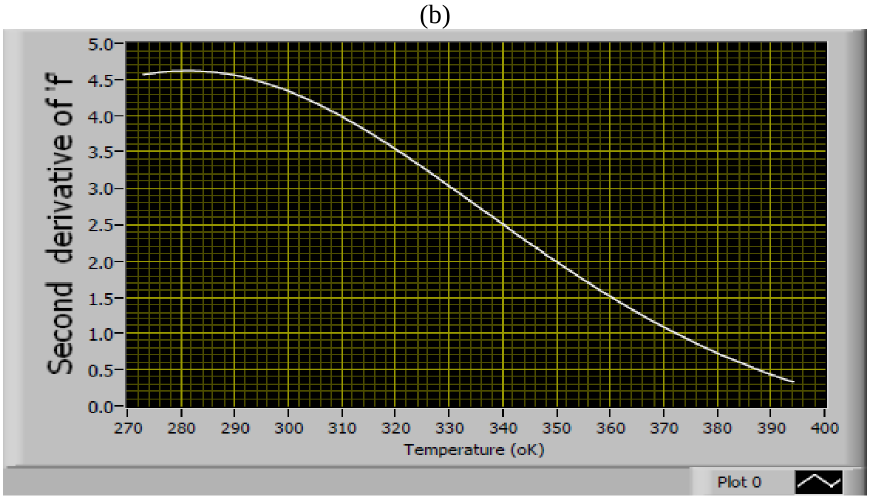
Fig. 2. Modified 555 Timer



(a)



(b)



(c)

Fig.3. (a) connection circuit characteristic f =F (T). (b) First derivative. (c) Second derivative

Table 1. Thermistor parameters used for the simulations.

Thermistor	**Material /Type**	**B25/85,K**	**Resistance at 25°C**
Therm 1	V2O5	2109	2.4 kΩ
Therm 2	NTC thermistor Philips	3977	4.7kΩ
Therm 3	NTC thermistor Philips	4190	47kΩ

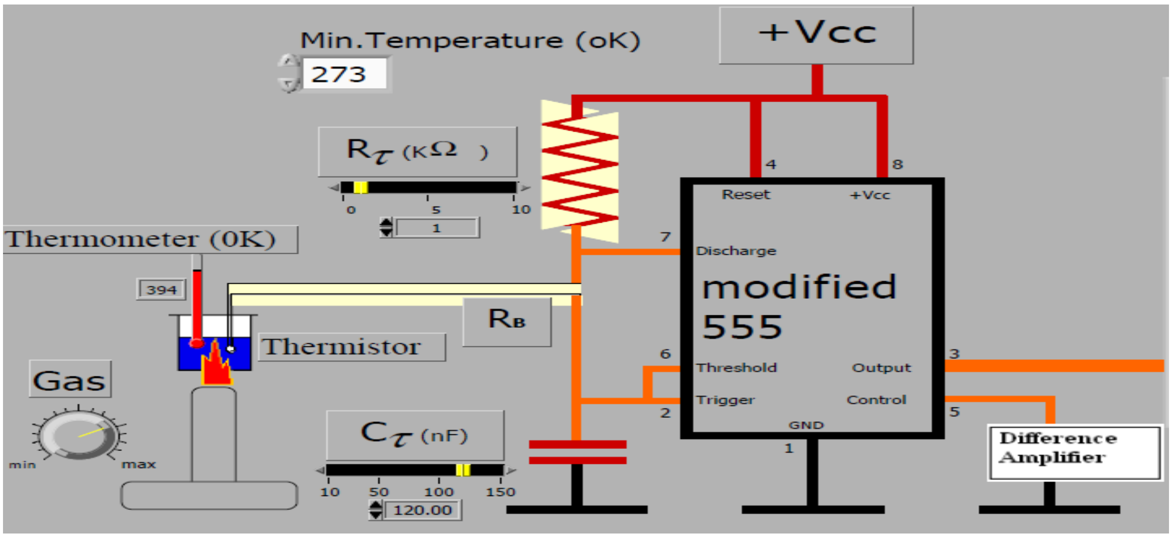


Fig.4. Front panel diagram showing the connection of thermistor.

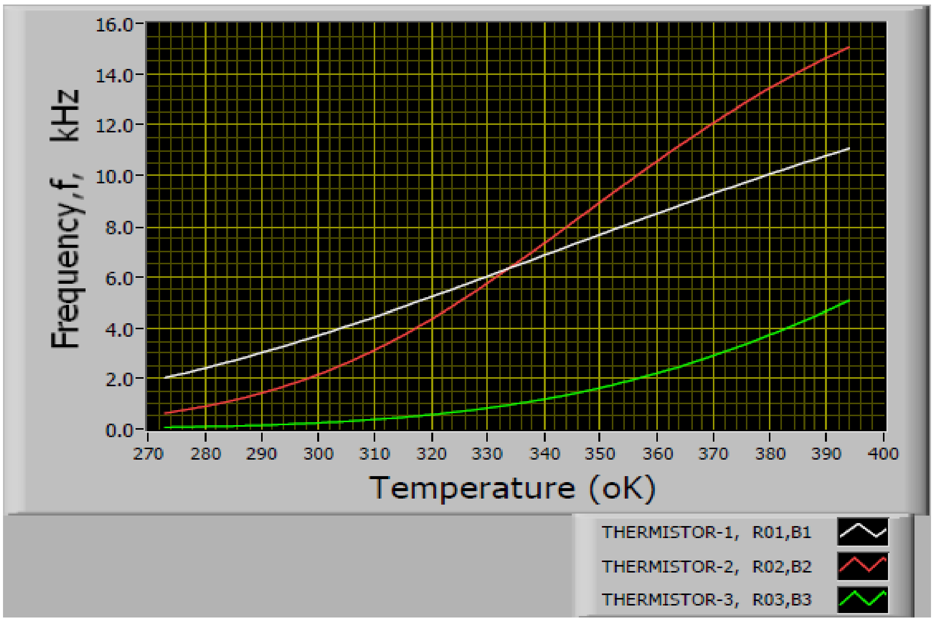


Fig.5. Simulated characteristic of thermistor (Rτ=1000Ω, Cτ=120nF)

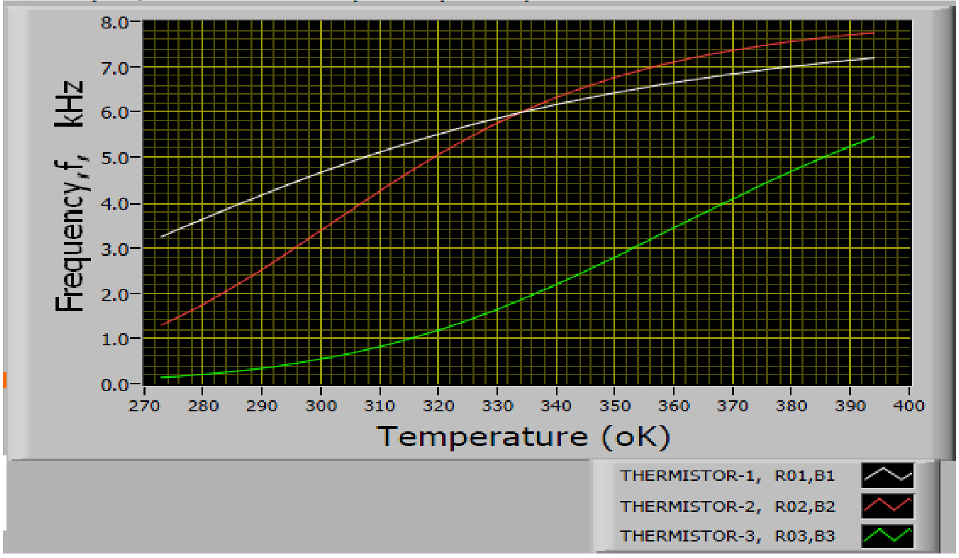


Fig.6. Simulated characteristic of thermistor (Rτ=6000Ω, Cτ=50nF)