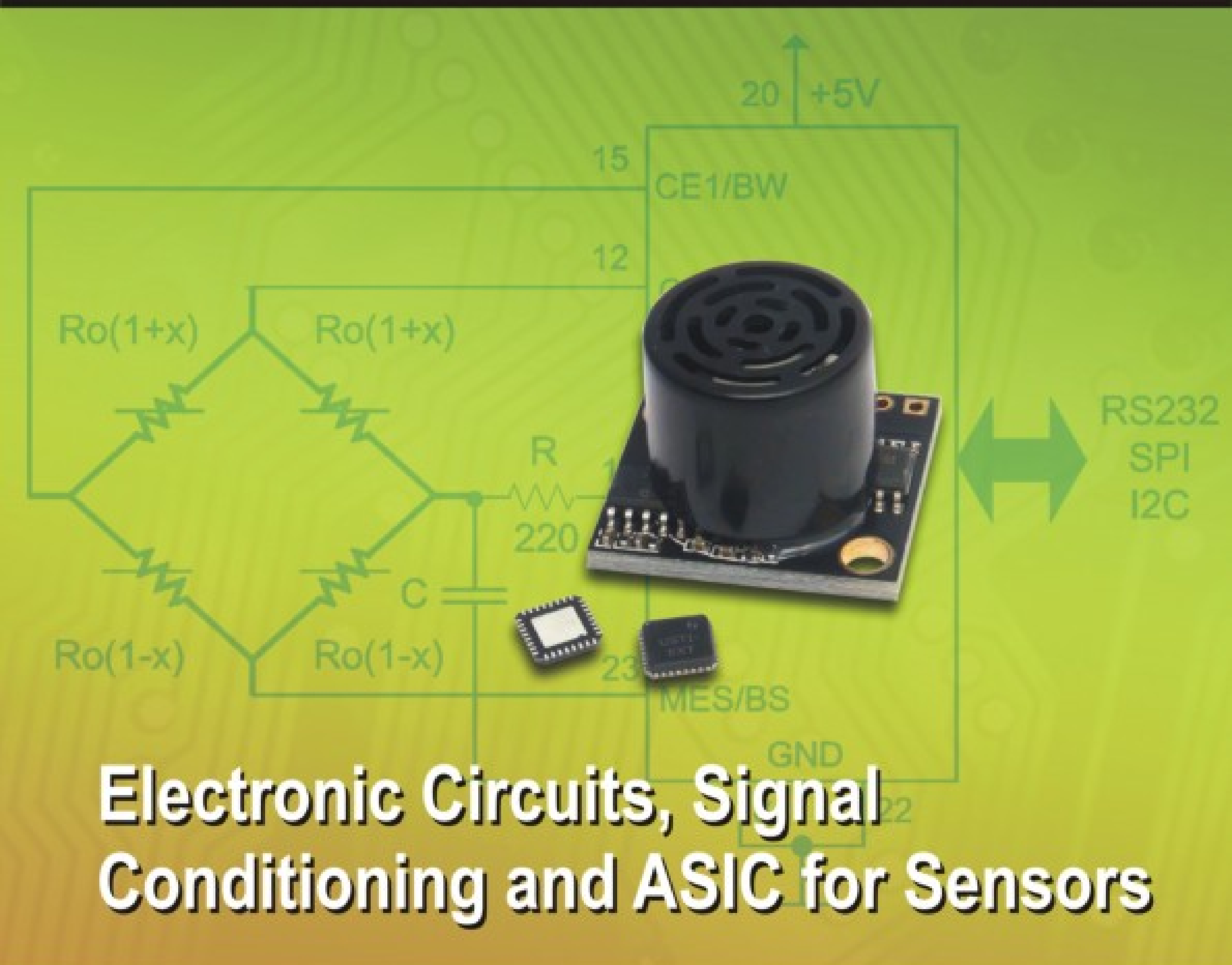
ISSN 1726-5479

SENSORS & TRANSDUCERS

vol. 141
6/12



Electronic Circuits, Signal Conditioning and ASIC for Sensors

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 141, Issue 6, June 2012 | www.sensorsportal.com | ISSN 1726-5479

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA).
Available in electronic and on CD.

Sensors & Transducers Journal

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June 2012

www.sensorsportal.com

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Sensors & Transducers Journal, Vol. 141, Issue 6, June 2012, pp. 17-25

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Design of Linearized Thermistor Connection Circuit Using Modified 555 Timer

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Received: 25 May 2012 /Accepted: 25 June 2012 /Published:30 June 2012

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 over a wide temperature range (0 °C to 120 °C) with reasonably good response linearity, reliability, and overall improved performance. 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. In a specific range of temperature the proposed circuit is characterized by high temperature stability, improved sensitivity and nonlinearity of about ± 1 %. *Copyright © 2012 IFSA.*

Keywords: Thermistor, Linearization, Modified 555 timer, Lab VIEW, Data acquisition, Temperature sensor.

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]. A novel method of linearizing thermistor characteristic using voltage controlled oscillator has been proposed which is characterized by nonlinearity of ±1% and sensitivity of about 5 kHz/^{o}C in a specific temperature range, as well as high temperature stability and reported by authors in [16].

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 [17, 18]. 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 data acquisition system.

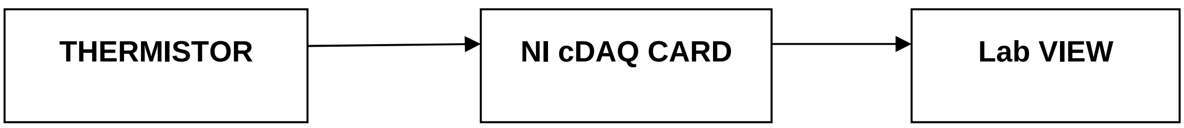


Fig. 1. Thermistor data acquisition system.

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)

$$R_T = R_o e^{B(\frac{1}{T}-\frac{1}{T_0})}, \tag{1}$$

where *B* is the "material constant" of the thermistor (expressed in Kelvins), which is determined by the activation energy *q and* the Boltzmann's constant *k* with the dependence *B=q/k* and ***T*** and T_0 are absolute temperatures in degrees Kelvin. R_o is the resistance of the thermistor at 25 °C (298 K). When the body temperature *T* of the thermistor is due solely to ambient heating, R_T reduces to *Ro* and defines the "zero-power resistance-temperature characteristic" of the thermistor. Although *B* increases slightly with increasing temperature, it may be considered constant over limited temperature spans of approximately 30 °C to 70 °C in width depending upon the thermistor material and the absolute temperature at which the center of the span is located [19].

The circuit of thermistor connection is given in Fig. 2. It uses the modified 555 timer circuit and has been built on the laboratory using discrete electronic components. The typical waveforms of the modified 555 timer circuit are shown in Fig. 3. By controlling the input signal (V_{con}), the output switching frequency (f) is adjusted; The expressions that describe the relationship among t_L, t_H, R_a, R_τ, C_τ and T_p are given by set of equations (2)-(4).

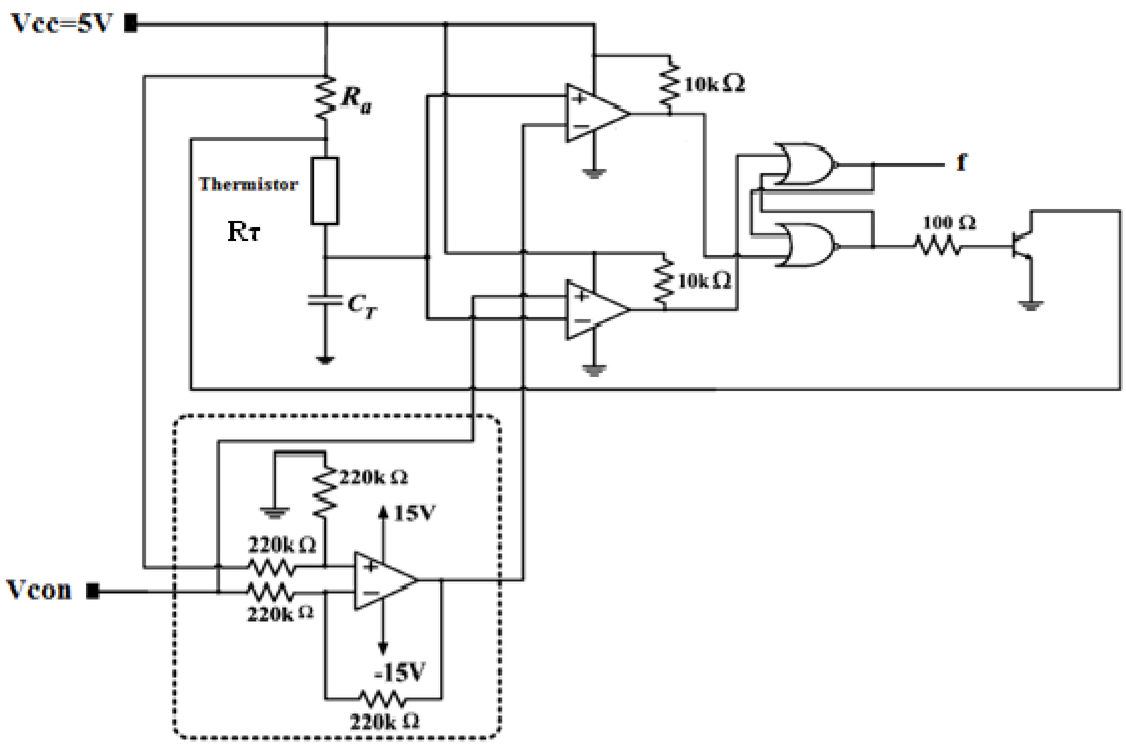


Fig. 2. Proposed circuit of modified 555 timer.

$$t_L = R_\tau C_\tau \ln\left(\frac{V_{cc} - V_{con}}{V_{con}}\right) \tag{2}$$

$$t_H = (R_a + R_\tau)C_\tau \ln(\frac{V_{cc} - V_{con}}{V_{con}}) \tag{3}$$

The period of the waveform is given by

$$T_p = t_L + t_H = \ln(\frac{V_{cc} - V_{con}}{V_{con}})(R_a + 2R_\tau)C_\tau \tag{4}$$

Therefore, the output frequency of the proposed circuit is given by the expression (5)

$$\text{f} = \frac{1}{\ln\left|\frac{V_{cc}}{V_{con}} - 1\right|(C_\tau(2R_\tau + R_a))}, \tag{5}$$

where R_τ is the resistance of thermistor and R_a and C_τ are the frequency determining elements. Therefore, the transformation function of the measurement circuit can be represented as

$$\text{f (T)} = \frac{1}{\ln\left|\frac{V_{cc}}{V_{con}} - 1\right|(C_\tau(2R_{T25}e^{B(\frac{1}{T}-\frac{1}{298})} + R_a))}, \tag{6}$$

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.

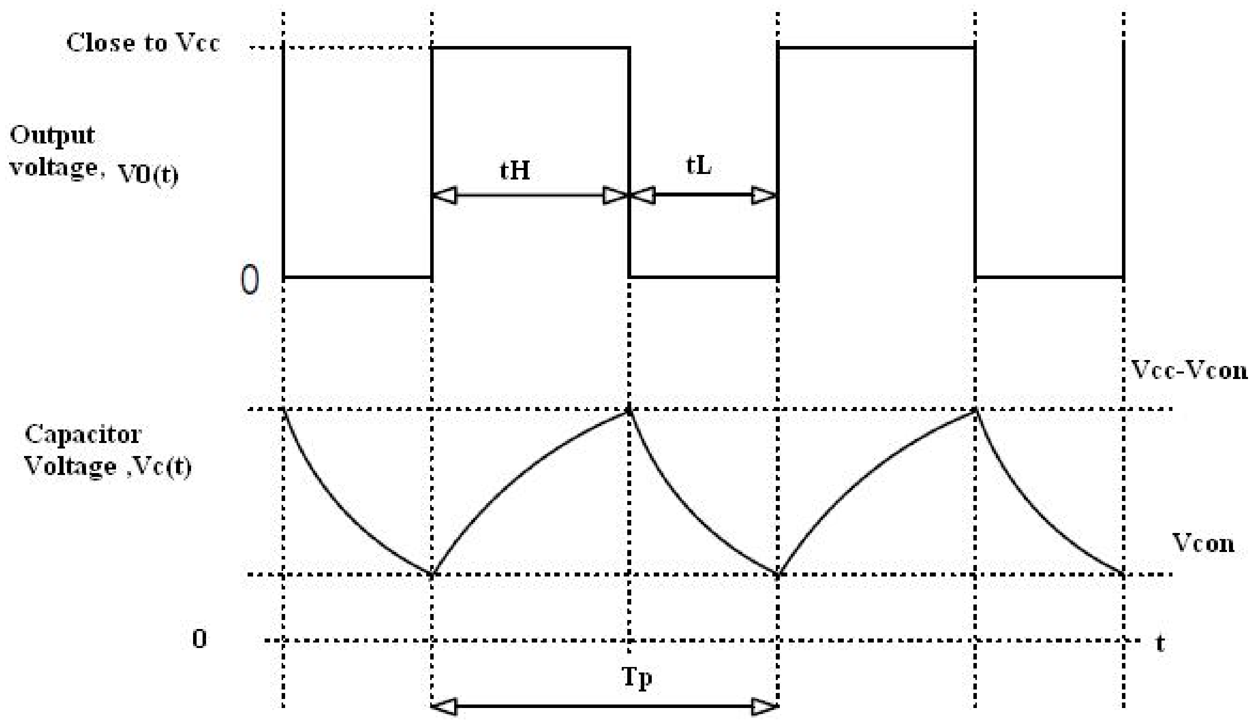
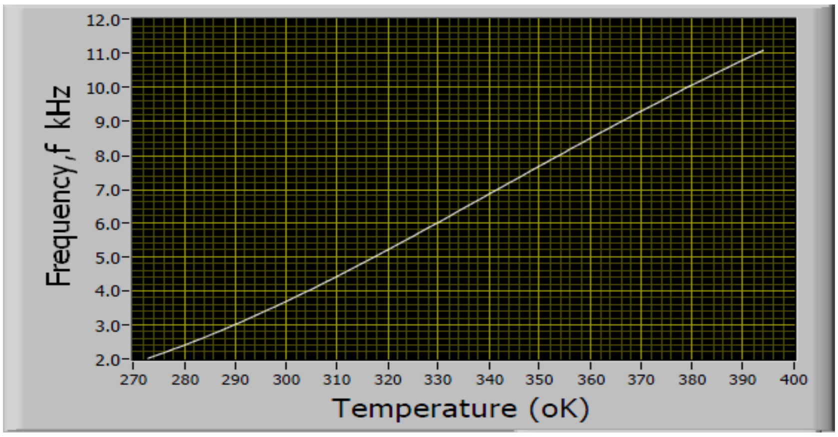
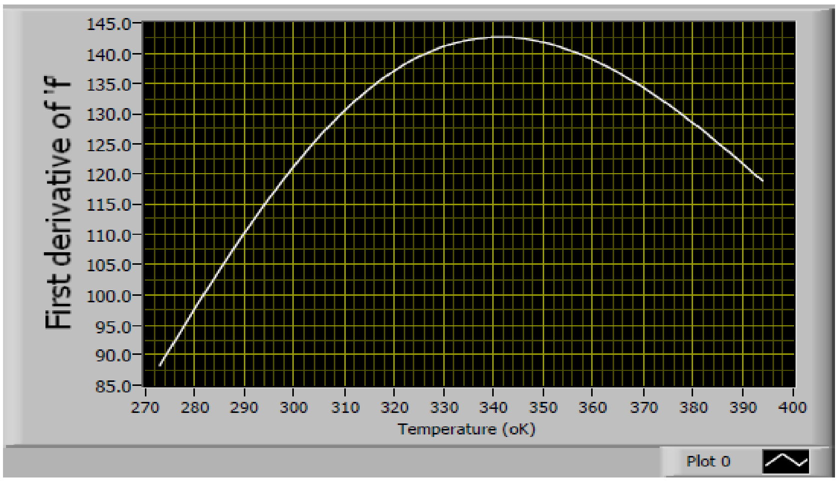


Fig. 3. Typical waveforms of the modified 555 timer circuit.

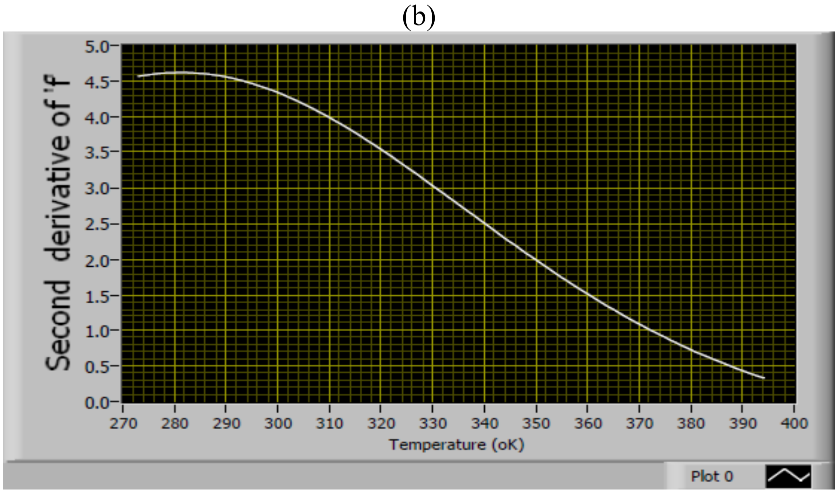
The graph of the transformation function given in Eq.(6) and their first and second derivatives with respect to temperature T, ($\frac{d(f)}{dT}$ and $\frac{d^2(f)}{dT^2}$ respectively) are shown in Fig. 4.



(a)



(b)



(c)

Fig. 4. Characteristic of thermistor connection circuit $f = F(T)$ (a); $\frac{d(f)}{dT}$ (b); Second derivative $\frac{d^2(f)}{dT^2}$ (c).

The above transformation function (6) 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 V_2O_5-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 [19, 20] are shown in Table 1.

Table 1. Thermistor parameters used for the simulations.

Thermistor	Material /Type	B25/85, K	Resistance at 25 °C
Therm 1	V_2O_5	2109	2.4 kΩ
Therm 2	NTC thermistor Philips	3977	4.7 kΩ
Therm 3	NTC thermistor Philips	4190	47 kΩ

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. 5.

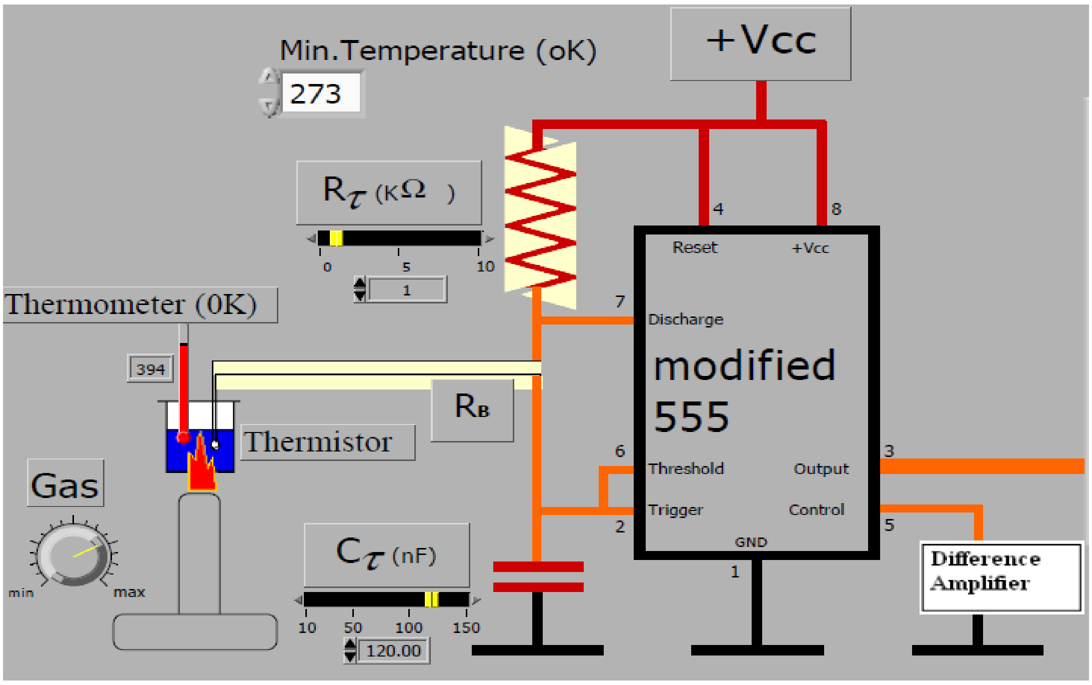


Fig. 5. Front panel diagram showing the connection of thermistor.

A simulation of the proposed circuit characteristic is conducted for thermistors with the parameters given in Table 1 at Rτ= 1000 Ω, Cτ=120 nF and V_{con}=2 V. The simulated results are shown in Fig. 6. 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=6000 Ω and Cτ=50 nF is shown in Fig. 7. the characteristic shows linearization for therm 3 in the range around 40 °C to 120 °C.

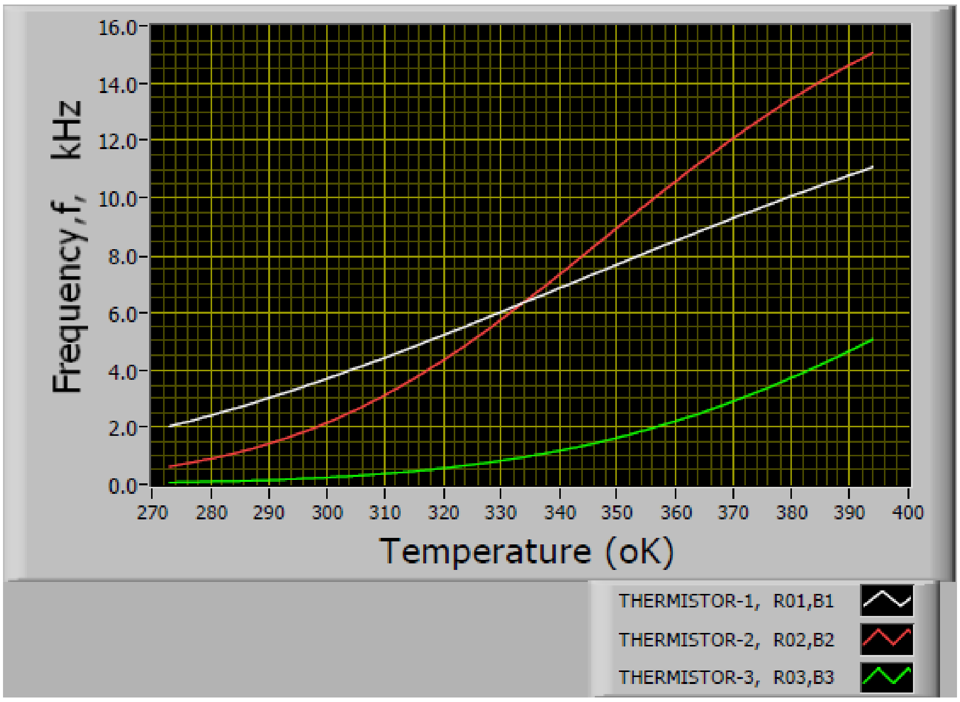


Fig. 6. Simulated characteristic of thermistors (Rτ=1000 Ω, Cτ=120 nF).

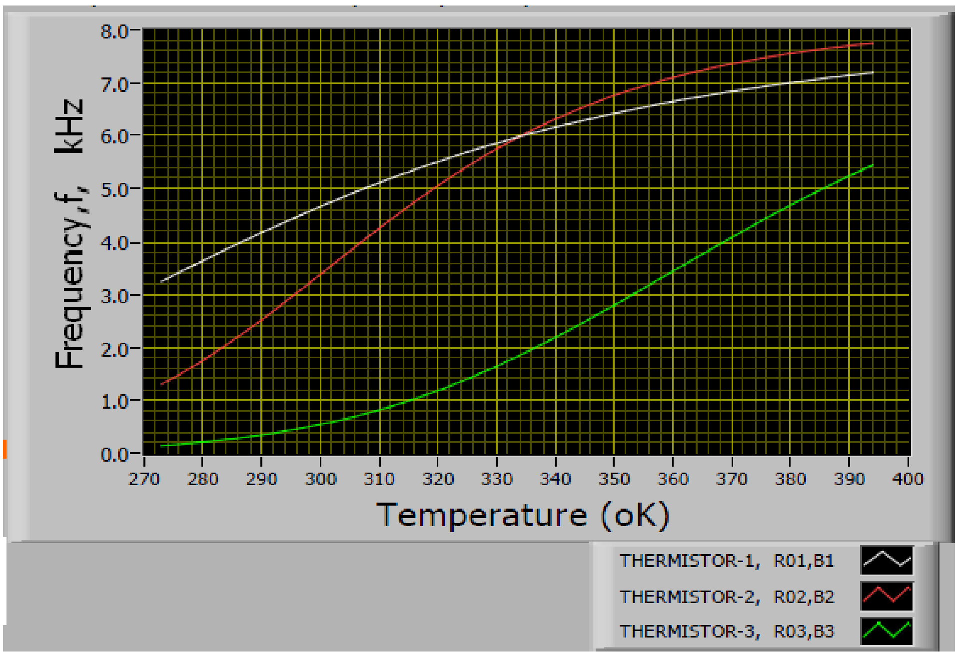


Fig. 7. Simulated characteristic of thermistors (Rτ=6000 Ω, Cτ=50 nF).

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 $C\tau$ of the timer, given the pre specified selected parameters of the thermistor and the frequency-determining resistance $R\tau$.
3) The sensitivity of the proposed instrument can be improved with the selection of control voltage preferably ranging from 0.5 V to 2 V.

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Guide for Contributors

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- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
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