THERMOSENSITIVE IC FOR RELATIVE TEMPERATURE DETERMINATION

Olexandra GOTRA[1], Wlodzimierz KALITA[2], Stanislav SLOSARČÍK[3], Alena PIETRIKOVÁ[3], Ján ŠALIGA[4]

[1] Department of Biophysics
Lviv State Medical University
Pekarska 69, 79010, Lviv
Ukraine

[2] Rzeszow University of Technology
W. Pola 3, Rzeszow
Poland

[3] Department of Hybrid Microelectronics
Technical University of Košice
Park Komenského 2, 041 21 Košice
Slovak Republic

[4] Dept. of Electronics and Telecommunications
Technical University of Košice
Letná 9/A, 04120 Košice
Slovak Republic

Abstract

The functioning algorithm and the scheme of the transducer unit applied in thermosensitive IC with relative temperature reading are proposed in this paper. The principal algorithm of functioning is in the formation of current with linear dependence on absolute temperature by additional transduction of current into differential signal with value determined by relative temperature scale.

Keywords

Thermosensitivity, transducer, IC (integrated circuit), temperature determination

1. Introduction

Weighty achievement of modern microelectronics is expansion of functional possibilities of sensor devices the prior of which are single chip ICs. On the up-to-date stage of development mono crystal sensor, ICs are used for measuring of temperature, magnetic field, stresses, force, pressure, flow etc. Thermosensitive ICs such as STP35 (Texas Instruments), AD 590 (Analog Devices), LM 3911 (National Semiconductor) are wide spread [1,2]. However, such ICs form the signal with value determined by absolute temperature. The measurement of relative temperature on the base of those thermosensitive ICs is not effective enough. The requirement of signal, which value is determined by relative temperature, is considerable especially in biomedical electronics, environmental monitoring, etc.

Results of elaboration of functioning algorithm and scheme of transducer of bipolar thermosensitive IC with relative temperature reading are presented in this paper.

2. The principle of thermosensitive IC function

The conceptual diagram and suggested detailed electric scheme of thermosensitive IC for determination of relative temperature is shown in Fig. 1.

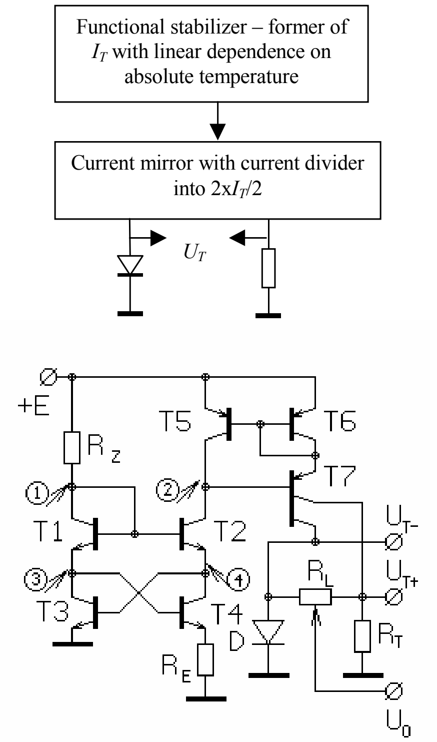

Fig. 1 Conceptual diagram and detailed electrical scheme of base variant of transducer with relative temperature reading

The main parts of the transducer are:

1. Functional stabilizer - former of I_T on the T_1-T_4, R_E, R_Z,
2. "Current mirror" - divider on T_5-T_7,
3. Formatting elements of relative temperature conductive scale D, R_T, R_L.

It can be proven at special conditions that the output differential voltage U_T depends only on relative temperature in arbitrary temperature scale. To prove this statement, the following analysis can be carried out.

Let us consider the generally known principle of current stabilizer functioning. According to its diagram in Figure 1, following system of basic equations can be fixed

$$\begin{cases} U_1 = U_{be2} + U_{be3} \\ U_1 = U_{be1} + U_{be4} + I(R_E) \cdot R_E \\ I_Z = I(R_Z) \approx I_{c1} \approx I_{c3} \\ I_T = I_{c2} \approx I_{c4} \approx I(R_E) \end{cases} \tag{1}$$

where U_{bei} are voltages on emitter p-n junctions of transistors (T_i) and I_{ci} are output (collector) currents of transistors (T_i).

Taking into account that the current-voltage characteristics (CVC) can be simplified for silicon p-n junctions at $U_{be} >> \varphi_T$ voltages, i.e. at normal voltages of their direct bias.

$$I_i = I_{0i}\left(\exp\frac{U_{bei}}{m\varphi_T} - 1\right) \approx I_{0i}\exp\frac{U_{bei}}{m\varphi_T} \Rightarrow \tag{2}$$
$$U_{bei} = m\varphi_T \ln\frac{I_i}{I_{0i}}$$

where I_{0i} is the saturation current, $\varphi_T = k \cdot T/q$, m is factor of nonideality of p-n junction, k is Boltzmann constant, q is electron charge and T is absolute temperature.

From (1) and (2) equation (3) can derived

$$I_T = I(R_E) = \frac{U_{be2} + U_{be3} - U_{be1} - U_{be4}}{R_E} = \tag{3}$$
$$= \frac{m\varphi_T}{R_E}\ln\frac{I_2 \cdot I_3 \cdot I_{01} \cdot I_{04}}{I_{02} \cdot I_{03} \cdot I_1 \cdot I_4} = \frac{m\varphi_T}{R_E}\ln\frac{I_{01} \cdot I_{04}}{I_{02} \cdot I_{03}}$$

Considering that the active area of T_1-T_3 transistors and the electro-physical parameters of their structure are mutually identical, $I_{01}=I_{02}=I_{03}=I_0$. Let the active area of T_4 emitter is p times larger than T_1-T_3 emitter area, then $I_{04} = p \cdot I_0$. The equation (3) can be rewritten into the following form

$$I_T = \frac{m\varphi_T \ln p}{R_E} = \frac{mk \ln p}{rR_E} T \tag{4}$$

Current I_T is, in the first approximation, independent on the supply voltage and on the current through resistor R_Z, i.e. the non-stabilized supply voltage E can be used. The I_T value is characterized by linear dependence on the absolute temperature T. The transconductance of this dependence is

$$\frac{dI_T}{dT} = \frac{mk \ln p}{qR_E} \tag{5}$$

and the output voltages of transducer are

$$U_{T+} = \frac{R_T}{R_E} \cdot \frac{mk \cdot \ln p}{2q} \cdot T \tag{6}$$

$$U_{T-} = m\varphi_T \cdot \ln\frac{I_T}{2I_{0D}} \tag{7}$$

Let us determine the temperature factor of this voltage (TFV)

$$\frac{dU_{T+}}{dT} = \frac{R_T}{R_E}\frac{mk \cdot \ln p}{2}; \tag{8}$$

$$\frac{dU_{T-}}{dT} = \frac{d}{dT}\left(\frac{mkT}{q}\ln I_T - \frac{mkT}{q}\ln I_{0D} - \frac{mkT}{q}\ln 2\right) \tag{9}$$

$$\frac{d}{dT}\left(\frac{mkT}{q}\ln I_T\right) = \frac{mk}{q}\ln I_T + \frac{mkT}{q}\frac{1}{I_T}\frac{dI_T}{dT} = \tag{10}$$
$$= \frac{mk}{q}(\ln I_T + 1);$$

$$\frac{d}{dT}\left(\frac{mkT}{q}\ln I_{0D}\right) = \frac{mk}{q}\ln I_{0D} + \frac{mkT}{q}\frac{d(\ln I_{0D})}{dT}; \tag{11}$$

Let C is a constant, E_{G0} is the width of forbidden gap of silicon the value of which is E_{G0}=1,205V at absolute zero temperature. Then

$$\ln I_{0D} = \ln C + 3\ln T - \frac{qE_{G0}}{kT}; \tag{12}$$

$$\frac{d(\ln I_{0D})}{dT} = \frac{3}{T} + \frac{qE_{G0}}{kT^2}; \tag{13}$$

$$\frac{d}{dT}\left(\frac{mkT}{q}\ln I_{0D}\right) = \frac{mk}{q}\left(\ln I_{0D} + 3 + \frac{qE_{G0}}{kT}\right); \tag{14}$$

$$\frac{d}{dT}\left(\frac{mkT}{q}\ln 2\right) = \frac{mk}{q}\ln 2; \tag{15}$$

$$\frac{dU_{T-}}{dT} = \frac{mk}{q}\ln\frac{I_T}{2I_{0D}} - \frac{2kk}{q} - \frac{mE_{G0}}{T} \tag{16}$$

$$\frac{dU_{T-}}{dT} = -\left(mE_{G0} - \frac{mkT}{q}\ln\frac{I_T}{2I_{0D}}\right)/T - \frac{2mk}{q}; \tag{17}$$

$$\frac{dU_{T-}}{dT} = -\frac{mE_{G0} - U_T}{T} - \frac{2mk}{q} \tag{18}$$

The carried out analysis shows that:

1. the TFV of output voltage of U_{T+} is positive and can be given by relation between resistors of R_T/R_E,
2. the TFV of U_{T-} voltage is negative and is determined by difference between the width of forbidden gap of semiconductor and the voltage drop on p-n junction.

Let us consider, that, at the reference temperature T_0 of relative scale, the output voltages U_{T+} and U_{T-} are identical and equal to

$$U_{OT-} = U_{OT+} = \frac{R_T}{R_E}\cdot\frac{mk\cdot\ln p}{2q}\cdot T_0 \qquad (19)$$

It allows to determine the relation R_T/R_E between resistors for such a condition

$$R_T = \frac{2U_{OT-}}{m\varphi_{TO}\ln p}R_E, \qquad (20)$$

where $\varphi_{T0}= k\cdot T_0/q$. For p=5, U_{OT-}=650 mV, the relation is R_T/R_E=31.

Let us reduce U_{T+} voltage to the reference temperature of T_0

$$U_{T+} = \frac{R_T}{R_E}\frac{mk(T_0+T-T_0)\ln p}{2q} = \frac{R_T}{R_E}\left(\frac{mkT_0\ln p}{2q}+\frac{mk(T-T_0)\ln p}{2q}\right); \qquad (21)$$

$$U_{T+} = \frac{R_T}{R_E}\frac{m\varphi_{T0}\ln p}{2}\left(1+\frac{T-T_0}{T_0}\right) \qquad (22)$$

By substitution of relation R_T/R_E, for $U_{0T-}=U_{0T+}$

$$\frac{R_T}{R_E} = \frac{2U_{OT-}}{m\varphi_{T0}\ln p}\quad , \qquad (23)$$

the following equation can be obtained

$$U_{T+} = U_{OT-}\left(1+\frac{T-T_0}{T_0}\right) = U_{OT-}\frac{T}{T_0} \qquad (24)$$

It allows to determine TFV (U_{T+})

$$\frac{dU_{T+}}{dT} = \frac{U_{OT-}}{T_0} \qquad (25)$$

For the reference temperature T_0 = 300 K, the TFV(U_{T+}) is with U_{T-}(300 K) = 600 mV, dU_{T+}/dT = 2.00 mV/K, with U_{T-}(300 K) = 650 mV, dU_{T+}/dT = 2.17 mV/K, for U_{T-}(300 K) = 700 mV, dU_{T+}/dT = 2.33 mV/K.

2.1 Simulation and experimental results

The examples of temperature dependencies of transducer output voltage $U_{OUT} = U_{T+} - U_{T-}$ for various values of reference temperatures and transconductance of transduction are given in Figure 2. The results of probe indicate that non-linearity of temperature characteristics of output voltage is less than 1% in the range of -25...+75^{0}C. The supply voltage of IC was over 3 V and the consumption current is up to 3 mA.

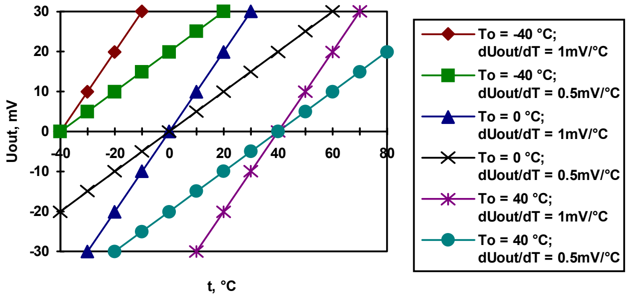

Fig. 2 The examples of temperature characteristics of transducer with relative temperature reading achieved by simulation.

It can be shown that by regulation of direct voltage on diode, for example by choosing area of diode, p factor of nominal of current-set resistor, the regime at which the conditions of $U_{OT+}=U_{OT-}$ and dU_{T+}/dT = -dU_{T-}/dT are fulfilled can be realised. It takes place at

$$\frac{E_{GO}-U_{OT-}}{T_0}+0{,}17=\frac{U_{OT-}}{T_0}, \qquad (26)$$

i.e. at

$$U_{OT-} = \frac{E_{GO}(mV)+0{,}17T_0}{2}. \qquad (27)$$

The conditions are fulfilled for T = 0 ^{0}C at U_{0T-}= 626 mV, for T = 27 ^{0}C (nominal temperature of “P-SPICE” modelling) at U_{0T-} = 628 mV, and for T = 35 ^{0}C (reference temperature for medical thermometer) at U_{0T-} = 629 mV.

The reference temperature dependent on voltage U_O is assigned by R_L potentiometer as

$$U_0=U_{T-}+(U_{T+}-U_{T-})\cdot(1-L), \qquad (28)$$

where $L\in(0,1)$ is the relative position from the midpoint of potentiometer. When TFV of U_{T-}, U_{T+} are equal, the reference voltage does not depend on temperature in the point of L = 0.5 and the value of reference voltage is $U_0=U_{OT-}=U_{OT}$.

3. Conclusions

The principle and the detailed electrical scheme of the transducer unit of thermosensitive IC with relative temperature reading are proposed. The algorithm functioning is in formatting of current with linear dependence on the absolute temperature by the further transduction of the current into differential signal the value of which is determined by relative temperature scale. In contrast to analogues, the temperature controlled voltage and reference voltage of proposed IC are formed in the single unit. The transducer is characterised by high linearity of transduction function, reproducibility of characteristics, minimum nonstability at the variation of supply voltage and simplicity of realisation scheme.

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About authors

Oleksandra HOTRA was born on December 29, 1965 in Lviv, Ukraine. In 1989 she graduated from Lviv Polytechnical Institute, Electrophysical Department, Department of Semiconductor Electronics on speciality Engineer of Electronic Technique. In 1996 she defended PhD. thesis on Solid State Physics. Now she works as Assistant Professor at Department of Biophysics of Lviv State Medical University and at Information Measuring Techniques Department of National University “Lviv Polytechnic”. Her field of interests is sensors of physical values on the base of integrated optics and electronics, liquid crystals and liquid crystal devices.

Włodzimierz KALITA was born in Poland in 1933. He graduated in electronics engineering from the Technical University in Wroclaw in 1958, and received a doctorate in electronics engineering and a doctorate in sciences from the Technical University of Lviv, Ukraine in 1992, respectively. Between 1958 and 1965 he worked at Transport Equipment Mfrg Centre, PZL – Mielec, Poland as Head of Avionics Department. Since 1965 he has been at Rzeszow University of Technology, where he is at present Associate Professor and Head of Department Electronic System. His major research interests are in the area of hybrid microelectronics, especially, analysis of temperature fields, tolerance, reliability and electromagnetic compatibility of microcircuits. He has published over 70 articles. He is a member of ISHM Poland and of the Editorial Board of Elektronizacja Journal.

Stanislav SLOSARČÍK (Doc., Ing., CSc.), was born in 1956. He graduated from the Slovak Technical University of Bratislava in 1980 and received CSc. (PhD.) degree in radioelectronics from the Technical University of Košice in 1987. He is Associate Professor of Hybrid Circuits Department, TU Košice, engaged in the research of sensors.

Alena PIETRIKOVÁ was born in Prešov, Slovakia, in 1956. She received MSc degree in physical metallurgy from the Metallurgical Faculty of Technical University in Košice in 1980 and the PhD degree in Material Engineering from Technical University in Košice in 1986. Since 1998 he is associate professor at FEI TU in Košice. Her interests include thick film and electronic material, thick film technology, thick film sensors.

Ján ŠALIGA was born in 1958. He received Ing. degree in Electrical Engineering in 1982 and PhD in Radioelectronics in 1995 from the Technical University in Košice. Since 1984 he has been assistant professor at Technical University in Košice, Dept. of Electronics and Multimedial Telecommunication. His research is focused on ADC and DAC testing methodology, general measurement methods, virtual instrumentation, distributed measurement systems.