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OPTIC-FREQUENCY TEMPERATURE SENSOR

The paper considers optoelectronic devices for temperature measuring, which comprise a great number of various units. High technical and operational characteristics of optic temperature sensors allow to use them in different fields of economy, science and technology.

***Key words**: optic-frequency and temperature sensor, negative resistance, temperature sensor, voltage-frequency converter, temperature, resistance capacitive reactance, passive inductance.*

Improvements of semiconductor technology allows to expand the sensors usage sphere and increase measuring accuracy, performance, reliability, durability, convenience of coordination with electronic measurement schemes.

Large spread character of sensors manufacturing promotes their price reduction, predetermining wide practical application. Such parameters as flow and level can be defined by means of temperature measuring.

Usage of modern microelectronic technologies resulted in considerable successes in creation of different control devices. But often obtaining of high metrological characteristics of the unites is achieved by enhancement of complexity, dimensions, weight and price. It is necessary to use new physical phenomena, and search new principles of device realization, characterized by multi functionality, have small consumption power, stability of characteristics, high sensitivity, increased performance and reliability for further improvement of primary converters quality.

Important type of sensors are temperature sensors since many processes are regulated according to temperature values. For measurement of temperature semiconductor or microelectronic sensors, manufactured in the form of microcircuits, infrared sensors, resistance thermometers, thermistors, thermocouples are used nowadays. . Usage of temperature sensors, as a rule, is based on measuring of dependence of electric resistance on the temperature, except thermocouple-based sensors , where electromotive force (EMF) appears, is proportional to resistance.

Principle of optical - frequency temperature sensor operation is based on temperature change action, received by temperature sensor IRA–E420S1produced by firm Murata (photoelectric, infrared sensor). Thus, output voltage on sensors is changed, this leads the changing of capacitive component with of complete resistance on the electrodes of collector-collector of bipolar transistors pair, that brings the change of resonance frequency of oscillatory circuit (Fig. 1).

Suggested device is composed of temperature sensor and voltage- frequency converter. When temperature does not change, measurements are not performed. At the moment, when negative resistance appears on electrodes collector – collector of bipolar transistors pair, it results in emergence of electric oscillations in the circuit (circuit is composed by parallel connection of the impedance with capacitive character on electrodes collector – collector of bipolar transistors pair VT1, VT2 and passive inductance L).

During the next temperature change, which is received by the sensor, its output voltage changes and it changes capacitive component of the impedance on electrodes collector-collector of bipolar transistors pair which entails the change of oscillatory circuit resonance frequency.

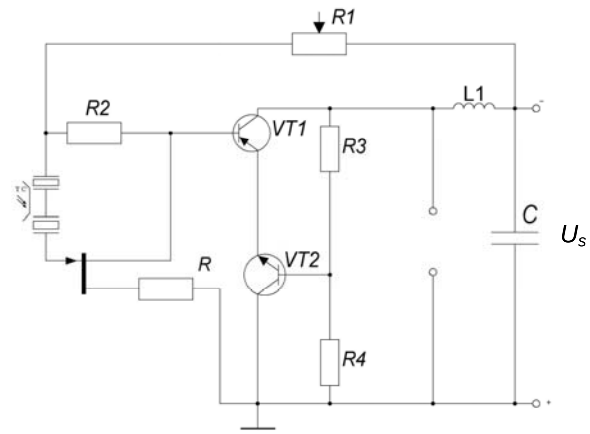

Fig. 1. Electric circuit of optic-frequency temperature sensor

Device, shown in Fig. allows to solve the problem of remote temperature measurement. There is a necessity in theoretical and practical proof that the resistance is on electrodes collector – collector of bipolar transistors, which corresponds to falling section of voltage-current characteristic (VCC). Besides, for studying the operation of optic-frequency temperature sensor in dynamic mode, it is necessary to obtain dependence of active and reactive component of complex impedance of electrodes collector – collector structure.

To realize this, we show the diagram of the device, taking into account equivalent circuits of transistors. We obtain diagram in Fig 2.

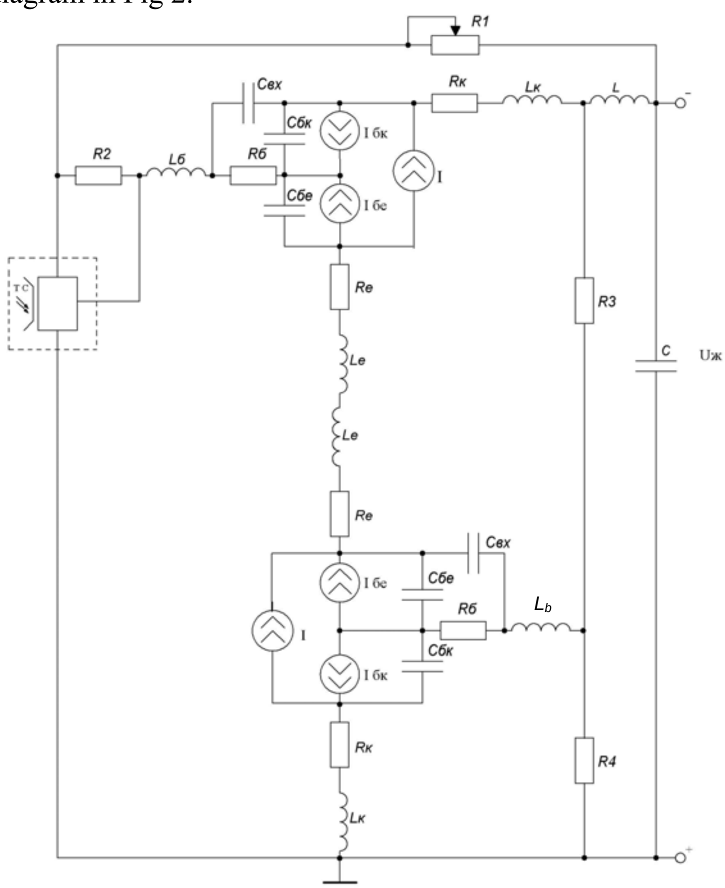

Fig. 2. Equivalent circuit of optic – frequency temperature sensor

For convenience of calculations simplified equivalent circuit of optic – frequency temperature sensor is shown in Fig 3.

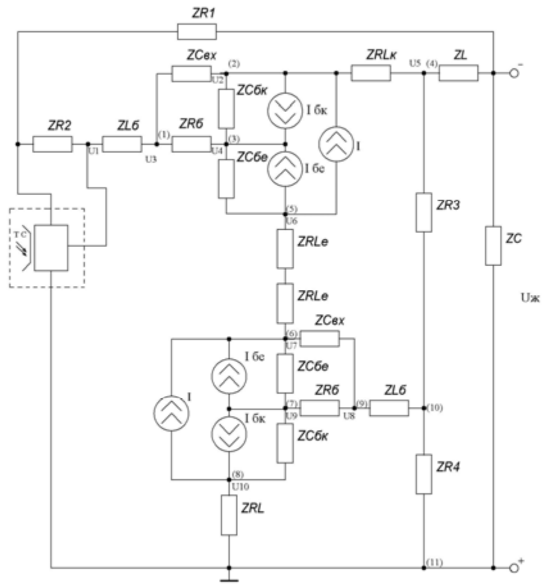

Fig. 3. Simplified equivalent circuit of optic – frequency temperature sensor

Let us perform calculation of the given mathematical model on the basis of node potentials method, and solve equations system.

$$
\begin{cases}
\dfrac{U_1}{Z_{R2}+Z_{LБ}}+\dfrac{U_2}{Z_{CBX}}-\dfrac{U_3}{Z_{RБ}}=0 \\[2ex]
-\dfrac{U_2}{Z_{CBX}}-\dfrac{U_2}{Z_{CБК}}+\dfrac{U_5}{Z_{RLK}}=I-I_{БК} \\[2ex]
\dfrac{U_2}{Z_{CБК}}+\dfrac{U_3}{Z_{RБ}}-\dfrac{U_4}{Z_{CБЕ}}=I_{БК}+I_{БЕ} \\[2ex]
\dfrac{U_Ж}{Z_C+Z_L}-\dfrac{U_5}{Z_{RLK}}-\dfrac{U_Ж}{Z_{R3}}=0 \\[2ex]
\dfrac{U_4}{Z_{CБЕ}}-\dfrac{U_6}{2Z_{RLБ}}-=-I_{БЕ}-I \\[2ex]
\dfrac{U_6}{2Z_{RLE}}-\dfrac{U_7}{Z_{CBX}}-\dfrac{U_7}{Z_{CБЕ}}=I+I_{БЕ} \\[2ex]
\dfrac{U_7}{Z_{CБЕ}}+\dfrac{U_8}{Z_{RБ}}-\dfrac{U_9}{Z_{CBK}}=-I_{БК}-I_{БЕ} \\[2ex]
\dfrac{U_9}{Z_{CBK}}-\dfrac{U_{10}}{Z_{RLK}}=I_{БК}-I \\[2ex]
\dfrac{U_7}{Z_{CBX}}+\dfrac{U_{11}}{Z_{RLБ}}-\dfrac{U_8}{Z_{RБ}}=0 \\[2ex]
\dfrac{U_Ж}{Z_{R3}}-\dfrac{U_{11}}{Z_{RLБ}}-\dfrac{U_Ж}{Z_{R4}+Z_{R3}}=0 \\[2ex]
\dfrac{U_Ж}{Z_{R4}+Z_{R3}}-\dfrac{U_Ж}{Z_C}+\dfrac{U_{10}}{Z_{RLK}}-\dfrac{U_1}{Z_{R2}+Z_{LБ}}=0,
\end{cases}
\qquad (1)
$$

where $Z_{R2} = R_2; Z_{R3} = R_3; Z_{R4} = R_4$; $Z_{RБ} = R_Б; Z_{LБ} = j\omega L_Б$; $Z_{CBX} = \frac{-j}{\omega C_{BX}}$; $Z_{RLK} = R_K + j\omega L_K$; $Z_{CБК} = \frac{-j}{\omega C_{БК}}; Z_{CБЕ} = \frac{-j}{\omega C_{БЕ}}$; $Z_{RLE} = R_E + j\omega L_E$.

Currents of base -emitter $I_{БЕ}$ and base- collector $I_{БК}$ are described by expressions:

$$I = \frac{I_{БЕ} - I_{БК}}{Q}, \tag{2}$$

$$I_{БЕ} = I_S \exp\left(\frac{U_{БЕ}}{NE \cdot V_t} - 1\right), \tag{3}$$

$$I_{БК} = I_S \exp\left(\frac{U_{БК}}{NC \cdot V_t} - 1\right), \tag{4}$$

$$I_S = I_{SS} \exp\left(\frac{U_{jS}}{NS \cdot V_t} - 1\right), \tag{5}$$

where Q – charge in base; $V_t = kT/q$; I_{SS} – reverse current of p-n junction of the base; $U_{БЕ}$ – voltage emitter – base; $U_{БК}$ – voltage base-collector; U_{jS} – potentials contact potentials difference of collector – base junction; NE – idealness factor of emitter junction; NC –non-ideality factor of collector junction; NS -non- ideality factor of base junction.

Having solved the obtained equation system, we will define the expression for the impedance of optic – frequency temperature sensor, which will have the following form:

$$Z = \frac{U_Ж}{\frac{Z_{R2} + Z_{RLE}}{Z_{LБ} - Z_{RLE}} \cdot \left[U_{:Ж}\left(\frac{1}{Z_C} + \frac{1}{Z_{R3}}\right) - 2I_{БЕ} - I + I_{БК} - \frac{Z_{CБК} + Z_{CBX}}{Z_{CБК} \cdot Z_{CBX}}\left(U_Ж\left(\frac{1}{Z_C + Z_L} - \frac{1}{Z_{R3}}\right) - I - I_{БК}\right)\right]} \tag{6}$$

Having substituted the values of equivalent circuit parameters in the obtained expression, we will get numerical value of the impedance $Z = -20 + j4{,}5$ KOhm (for $U_s = 8$ V).

Theoretical and experimental research showed, that active component of complex impedance of the circuit takes negative value, as it is shown in Fig 4. In its turn, reactive component of complex impedance of the circuit is of a capacitive character (Fig 5).

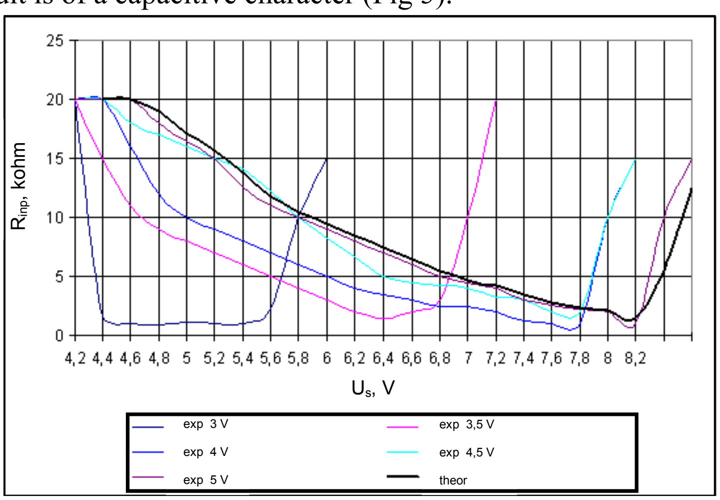

Fig. 4. Theoretical and experimental dependences of active component of complex impedance on power supply (at different control voltages 3 V; 3,5 V; 4 V; 4,5 V; 5 V)

As Fig 4 shows, experimental dependence on active component of complex impedance on power supply has the form of a curve, which is falling, and after that is rising again, whereas theoretical dependence is rising and falling almost by linear law.

As it follows from Fig 5, with the growth of power supply voltage reactive component reduces step-by-step (approximately to 4 KOhm level)

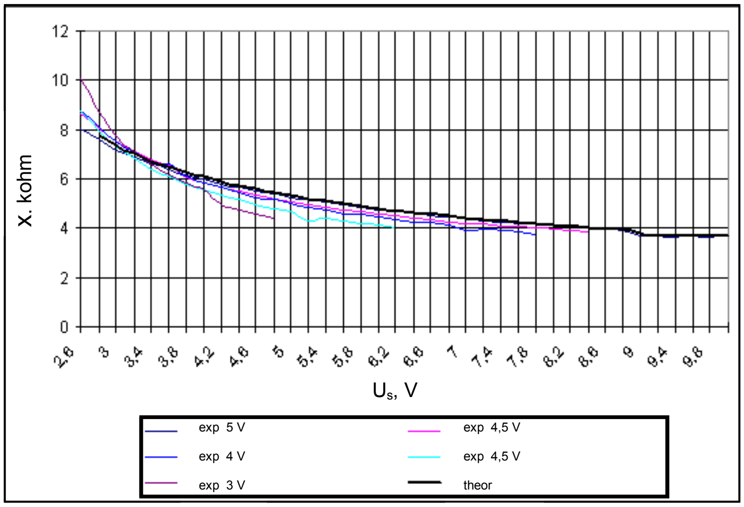

Fig. 5. Theoretical and experimental (at different control voltages 3 V; 3,5 V; 4 V; 4,5 V; 5 V) dependences of reactive component of complex impedance on power supply voltage

Connecting of passive inductance to collector – collector structure terminals in case of negative values of complex inductance (with compensation of power losses in oscillatory circuit) allows to create the generator of electric oscillations. When temperature change acts on the sensor change of active and reactive components of complex impedance occurs, that, in its turn, changes generation frequency. Fig 6 shows experimental dependence of generation frequency on voltage supply and has linear character.

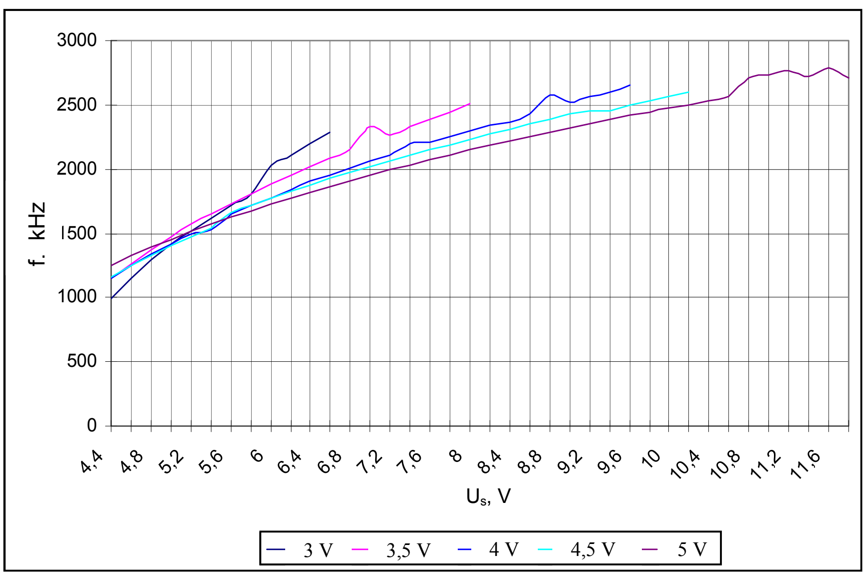

Fig. 6. Experimental dependence of generation frequency on power supply voltage

Fig . 7 shows experimental dependence of generation frequency on the temperature (at different control voltages), which is of almost linear character. When the control voltage equals 3,5 V, then the section from 100°C to 240°C is the most stable , for control voltage of 4,5 V the section from

35°C to 180°C is the most stable , and for 5 V – section from 35°Cto 160°C.

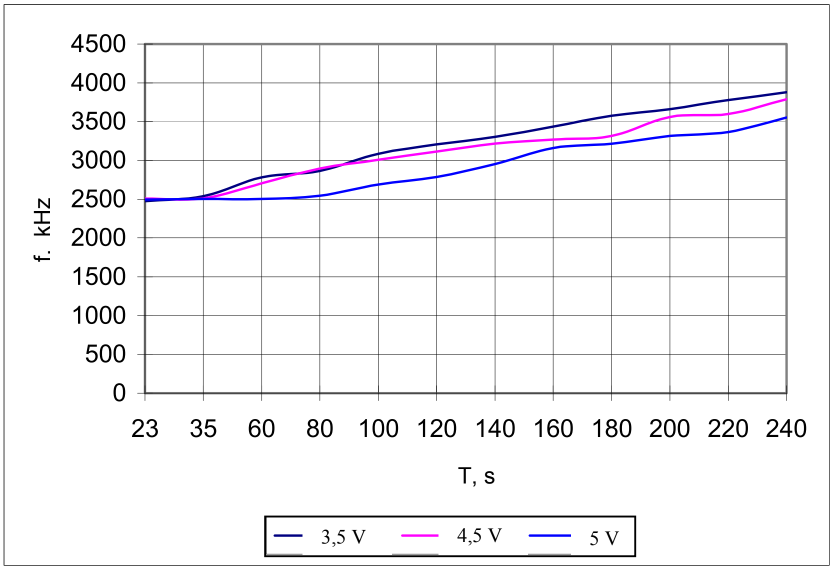

Fig. 7. Experimental dependence of generation frequency on the temperature.

A number of research has been performed. Carrying out calculation of optic-frequency temperature sensor circuit it was revealed that active component of complex impedance takes negative value and reactive component has a capacitive character and depends on power supply voltage. A number of interrelations between generation frequency and supply voltage, generation frequency and temperature is established.

REFERENCES

1. Поскачей А. А., Чубаров Е. П. Оптико-электронные системы измерения температуры. – М.: Энергоатомиздат, 1988. – 246 с.

2. Осадчук В. С., Осадчук А. В., Кравчук Н. С. Микроэлектронные сенсоры температуры с частотным выходом. – Винница: УНИВЕРСУМ-Винница, 2007. – 163 с.

3. Осадчук А. В. Микроэлектронные частотные преобразователи на основе транзисторных структур с отрицательным сопротивлением. – Винница: УНИВЕРСУМ-Винница, 2000. – 302 с.

4. Пат. 33239 Украина. МПК7 G 01 K 5/00. Оптический сенсор температуры с частотным выходом / Осадчук В. С., Осадчук А. В., Деундяк В. П., Деундяк Г. В.; заявитель и патентообладатель Винницкий национальный технический университет. – № u200802333; заявл. 22.02.2008; опубл. 10.06.2008, Бюл. № 11.

5. Пат. 33240 Украина. МПК7 G 01 K 11/00. Микроэлектронный оптический сенсор температуры с частотным выходом / Осадчук В. С., Осадчук А. В., Деундяк В. П., Деундяк Г. В.; заявитель и патентообладатель Винницкий национальный технический университет. – № u200802335; заявл. 22.02.2008; опубл. 10.06.2008, Бюл. № 11.

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