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Radio SAW - Sensors for Physical Parameters Measurement

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ABSTRACT
The schemas of wireless passive sensors on surface acoustic waves (SAW) for remote temperature and humidity measurements are presented. Presented sensors constructions, comparatively with existing analogues, allow to increase of measurement accuracy and to avoid a direct influence of environmental factors on sensors surfaces. Principles of operation, according to presented schemas sensors operation are described. The main constructive parameters of such sensors are given. The dependence of signal reflective coefficient of output transducers, loaded on external sensitive element, from impedance of external element is shown. With the help of presented sensor equivalent circuit dependence of amplitude of reflective signal from impedance of external sensitive to measuring physical quantity element is obtained.

Keywords: SAW sensor, temperature, humidity, thermistor, reflective coefficient.
PACS: 71.35; 73.20

INTRODUCTION

The SAW sensors nowadays are both independent measurement tools and simultaneously important parts of measurement systems, for example, the system of automatic control and technological processes management. The information, received from sensors, gives possibility to forecast the dangerous situations on controlled objects and even to avoid them. It is very important in thermal and nuclear power stations, chemical factories and others strategic objects. Sensors are the most important parts of measurement systems, therefore information credibility about state controlled objects depends on sensors characteristics and their reliable operations. Taking into account possible aggressive conditions of sensors operation, such as high temperature, humidity, radioactivity, systems control with cable lines and power sources in their constructions don't give warranty of avoiding dangerous situations on controlled objects. Therefore passive wireless sensors, based on the base of delay lines on SAW, are the most relevant for operation in such conditions. These sensors don't require power sources and cable lines for connection with devices of reception and processing measurement information and its are very stable in aggressive conditions.

Taking into account the information, presented above, improvement of the characteristics of existing sensors and development of new passive wireless sensors are the main tasks, which allow to increase reliability of measurement parameters control and controlled objects safety.

MATERIALS AND METHODS

Passive wireless sensors operation is based on interaction measurement parameter with sensitive to influence of this parameter delay line surface and modulated delayed signal receiving. This signal contains information about measurement parameter and is transmitted to device of reception and processing measurement information by radio channel [1-12]. The disadvantage of sensors [6-12] is necessity of direct contact of aggressive environment with surface delay line. This contact decrease duration of sensor using through possible foulness and sensors destruction and leads to signal loss. This disadvantage is absent in passive wireless SAW sensors with external sensitive to measurement parameters elements. Presented sensors [1-5] have piezoelectric sound-conductor with two transducers on its surface. First of transducers is connected with antenna, and second – with external sensitive to measurement parameters element. Operation of these sensors is based on dependence measurement physical parameter and reflective coefficient or reflective signal amplitude from connected with external element transducers. Therefore, parameters of signal, reflected from external element, contain information about values measurement parameter. Disadvantage of sensors, described in [4, 5], is dependence of their data from distance between antenna and device of reception and processing measurement information and their relativeposition.

Disadvantages of presented in [4, 5] sensors are absent in SAW sensor for temperature measurement (fig.1). This sensor contains piezoelectric sound-conductor (1) with situated on its surface two transducers and reflectors. First of transducers (2) is connected with antenna (3), other transducer (4)– with external sensitive to measurement parameters element (5). Reflectors (6) and transducers (2) are forming supporting delay line and supporting signal; transducers (2) and (4) are forming measurement delay line and measurement signal. For decrease wrong signal magnitude and traveling wave regime creation absorbers (7) are plotted on sound-conductor butt. Sensor with exception of external sensitive element (5) is placed in hermetic package (8). Reflectors with input/output transducer allow to create supporting signal avoiding dependence data sensors from distance between antenna and device of reception and processing measurement information and their relative position.

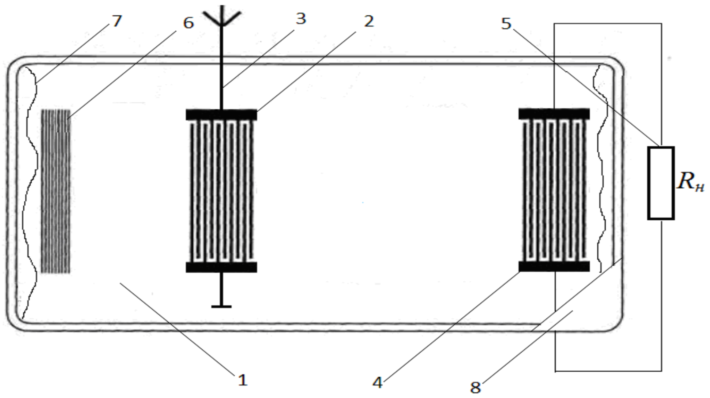

Fig.1. SAW sensor for physical parameter measurement

Request radio signal from the device of information reception and measurement processing coming to antenna (3). Transducer (2) due to the indirect piezoelectric effect excites in sound-conductor (1) distributing into both direction from transducer (2) surface acoustic waves . Part of SAW energy reflects from reflectors (6) and returns to transducer (2) and due to the direct piezoelectric effect transforms to electric signal. This signal is emitting in space by antenna (3). By this way supporting signal is formed. Delay time of supporting signal depend on distance between transducer (2) and reflectors (6) and SAW distribution velocity along sound-conductor surface. Part of SAW energy reflects from transducer (4), returns to transducer (2) and due to the piezoelectric effect transforms to electric signal. This signal is emitting in space by antenna (3) too. By this way the measurement signal is formed.

Reflective coefficient and reflective signal amplitude for transducer (4), loaded on thermistor (5), is depended from its conductance and from measurement parameter magnitude. Reflective coefficient is calculated according to relation [13]:

$$|\Gamma_{R_и}| = \frac{G_a(\omega_0)}{G_a(\omega_0) + Y_и + j\omega_0 C_T}, \tag{1}$$

where $G_a(\omega_0)$ - active part of transducer (4) conductance on central frequency; $C_t = NC_sW$ - static capacity transducer (4); N - electrodes pairs amount; ω_0 - central frequency; $Y_и$ - conductance of transducer load.

Therefore parameter of reflective from transducer (4) signal contains information about magnitude of the measurement temperature.

After supporting and measurement signals coming to device of reception and processing measurement information is done (for example correlation analysis and determination of supporting and measurement signals amplitudes). Therefore, forming of two signals allow avoids the influence of distance between antenna and device of reception and processing measurement information and their relative position, because attenuations of supporting signal and measurement signal due to the signals distribution are the same. Herewith for effective selection supporting and measurement signals delay time of these signals must be different.

To except described below constructive parameters:

- phase velocity SAW V = 3992 m/s (material sound-conductor – lithium niobate);
- central frequency f = 434 MHz;
- distance between transducer (2) and transducer (4) – 0.004 m; distance between transducer (2) and reflectors (6) – 0.002 m. It gives time delay measurement signal relatively time delay supporting signal – 1 mks;
- external sensitive element – thermistor MMT-12 with resistance 1 kOm, temperature sensitivity coefficient B = 4300 K^{-1}. Temperature dependence of resistance is determined according to relation (fig.2)[14]:

$$R = R_\infty e^{B/T}, \tag{2}$$

where B = 4300 K^{-1} - temperature sensitivity coefficient ; R_∞ - thermistor resistance at high temperature, Om; T – current temperature, K.

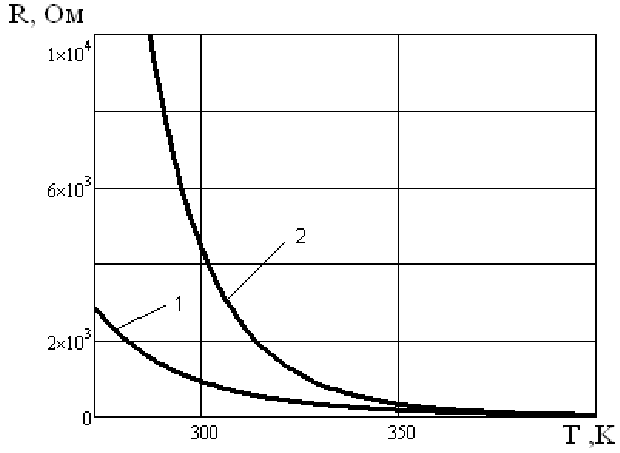

Fig.2. Temperature dependence of thermistor MMT-12 (1) та KMT-12 (2) resistance

According to relation (2) thermistor resistance at 100˚ C is 55 Om, therefore temperature change in range 25˚ C - 100˚ C leads to resistance change in range 1000 Ом - 55 Ом. Such resistance change leads to coefficient reflective change (1) leading to change of amplitude reflective signal at 18 dB relatively amplitude of signal reflected from reflectors.

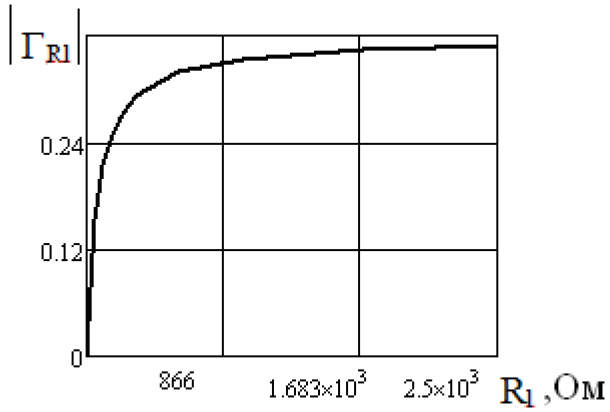

Fig.3. Dependence reflection coefficient module $|\Gamma_{Rl}|$from load impedance R_l

With using relation (1), amplitude of reflected from output transducer signal can be determined. For this definition below demonstrated sensor equivalent circuit is necessary (fig.4):

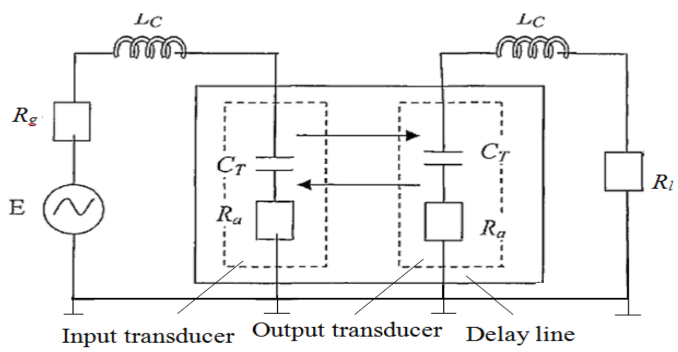

Fig.4. *Sensor equivalent circuit with connected to input transducer antenna (demonstrated by voltage source with internal resistance R_g) and connected to output transducer load resistance R_l*

According to upper showed circuit, voltage decreasing on input transducer resistance determines SAW amplitude. SAW distributes along delay line and is determined according to:

$$U_{Ra} = E \cdot R_a / (R_{\tilde{A}} + R_a + 1/i\omega C_T + i\omega L_C). \qquad (3)$$

Through double delay time, that is determined by distance between transducers and SAW velocity, sensor equivalent circuit will look according to fig. 5.
Now input transducer is signal source generating signal with voltage:

$$U_{2t\_delay} = U_{Ra} \cdot k \cdot \Gamma_{R_l} \cdot e^{-i2\omega t\_delay}, \qquad (4)$$

where k = ½ - coefficient, that includes loses due to the SAW distribution in both direction from transducer (is equal to attenuation 6 dB).
Then, voltage on antenna resistance R_g through double delay time determines informative signal amplitude in the place of sensor location and is equal to:

$$U_{Rg} = U_{2t\_delay} \cdot R_g / (R_g + R_a + 1/i\omega C_T + i\omega L_C) \qquad (5)$$

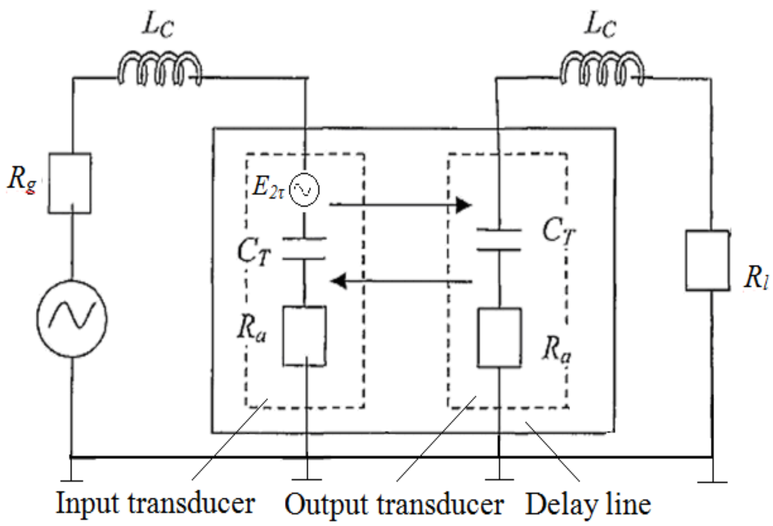

Fig. 5. Sensor equivalent circuit through double delay time

With using of relation (4) and (5) ratio U_{Rg} and E, that forms probing signal amplitude in starting point and is normalized voltage of informative signal:

$$A_{norm} = \frac{R_a \cdot R_g}{(R_g + R_a + 1/i\omega C_T + i\omega L_C)^2} \cdot k \cdot \Gamma_{Rl}. \qquad (6)$$

With taking into account antenna resistance magnitude (as rule, is equal to 50 Om) and value of inductance, that compensates value of capacitance C_t, (6) is equal to:

$$A_{norm} = \frac{R_a \cdot 50 \cdot k \cdot \left|\Gamma_{R_l}\right|}{(50 + R_a)^2} \qquad (7)$$

Therefore, using relation (1) and (7) dependence of measurement signal amplitude from output transducer load impedance (and measurement temperature value) is obtained. Measurement signal is generated by antenna in space and comes to device of reception and processing measurement information.

On the base of compassion of reflected from transducer (4) measurement signal amplitude and reflected from reflectors (7) supporting signal amplitude in device of reception and processing measurement information temperature is measured. So using of SAW sensor for temperature measurement with the demonstrated at fig.1 schema allows to avoid measurement temperature influence on sound-conductor surface due to the external sensitive element availability and allow to increase measurement process precision due to the reflectors availability.

The avoiding of measurement physical parameter influence on sound-conductor surface is important task when humidity sensor is designed too. Humidity SAW sensor operation with cowered by membrane-absorber sound-conductor and located on it two transducers [9], requires direct contact sound-conductor and measurement humidity. This contact has negative influence on measurement process accuracy and on sensor operation in general (reliability, lifetime). Such disadvantage can be avoided by the schema with external sensitive element using (fig. 6).

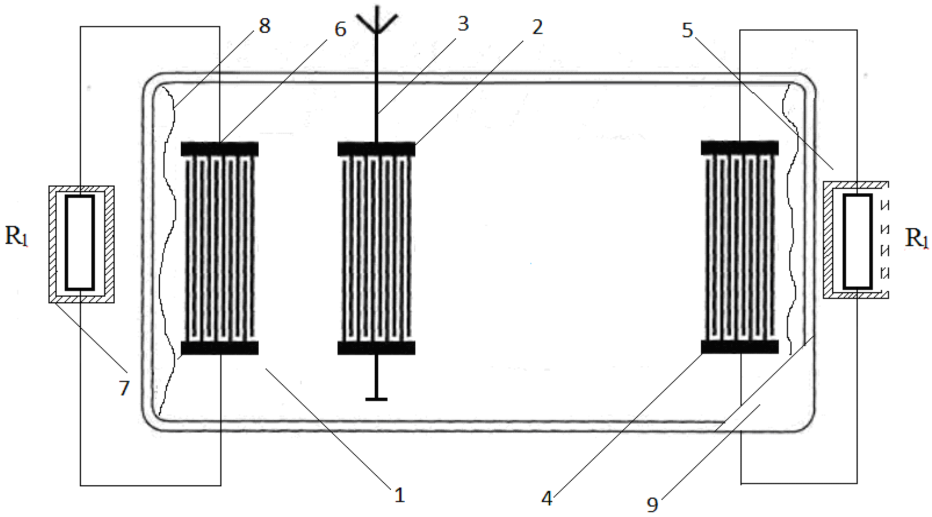

Fig. 6. Humidity SAW sensor

Humidity sensor (fig. 6) contains piezoelectric sound-conductor (1) with situated on its surface three transducers. First of transducers (2) is connected with antenna (3), other transducer (4)– with external sensitive to measurement parameter thermistor (5), third transducer – with located in hermetic package thermistor. For decrease wrong signal magnitude and traveling wave regime creation absorbers are plotted on sound-conductor butt. Sensor wit exception of external sensitive element is placed in hermetic package. Sensor wit exception of thermistor 5 is placed in hermetic package.

According to (1) reflective coefficient module (and reflective signal amplitude) from loaded on thermistor (5) transducer (4) depends on thermistor (5) conductance value and on temperature value.

Analogically dependence of reflective coefficient module (and reflective signal amplitude) from loaded on thermistor (7) transducer (6) is determined.

Whereas thermistor (5) is located in not hermetic package, environment humidity change leads to more temperature decreasing of thermistor (5) comparing with temperature of located in hermetic package thermistor (7). Temperature difference of thermistors (5) and (7) leads to their resistance difference and thereby reflective coefficient difference. Change of reflected from thermistor (5) signal amplitude relatively reflected from thermistor (7) signal amplitude contains information about measurement humidity value.

Taking into account presented above constructive parameters, change temperature in range 10˚ C - 45˚ C leads to resistance change in range 50 Om - 170 Om. Such resistance change leads to change of reflective coefficient module and amplitude reflected from loaded on thermistor transducer (4) signal on 10 dB relatively amplitude reflected from loaded on thermistor transducer (6) signal.

So comparison both signals magnitudes with the using of psychometric tables information about measurement humidity can be obtained. Herewith sensor data don't depend on measurement signal attenuation due to the distance between sensor and device of reception and processing measurement information and their relative position.

CONCLUSION

In the result of using showed above schemas for remote humidity and temperatures measurement accuracy of measurement process can be increased due to the supporting signal formation. Also negative influence of environment parameters on surface sound-conductor can be avoided due to the external sensitive element using.

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