Magnetoelectric current sensor: miniaturization and perspective

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Abstract. One of the main tasks of microelectronics is the miniaturization of devices with the keeping of previous functions and technical characteristics. In this paper, we present a magnetoelectric current sensor using a microprocessor. Compared with the previously presented magnetoelectric current sensor, we reduced the overall dimensions by almost 2 times and saved technical characteristics. Integration of the microprocessor opens up wide prospects for the application of the sensor in various industries, for example in robotics.

1. Introduction

An analysis of the world trends of current sensors indicates that such devices are in great demand today in various areas of industry. There is a massive replacement of traditionally used current sensors: shunts, current transformers, sensors on the Hall effect to modern miniature current sensors. There are searches for current sensors based on fundamentally new effects. In most modern sensors, current measurement is performed using magnetic fields, which provides their main advantages: galvanic isolation, high sensitivity, wide operating temperature range. Low price, small dimensions and at the same time high sensitivity contribute to the fact that they are beginning to be applied in measuring systems, security systems, the automotive industry, the railway industry, space technology, robotics and etc.

In most multiferroics (Cr_2O_3 and etc.) the magnetoelectric (ME) effect is not significant and its magnitude does not exceed α_E= E/H ~ 20 mV/(cm·Oe), and observed at low temperatures or in large magnetic fields, which limits their practical application. A significantly larger ME effect was observed in composite structures containing a magnetostrictive and piezoelectric phase. Thus, the use of composite structures opens up wide possibilities for practical application [1]. One of the main applications is high-sensitivity magnetic field sensors is magnetometers [2,3]. The current sensors are also a perspective trend. The previously presented magnetoelectric current sensor [4-6] has a significant disadvantage that is no digital output. ME current sensor is based on the magnetoelectric effect and designed to measure the current in electrical circuits of a direct current. The use of the ME effect allows us to solve a lot of problems and tasks facing us. The main applications of the sensor are measuring systems, safety systems, automotive industry, space technology, robotics.

The paper discusses the principle of operation, three-dimensional modeling of the case, a printed circuit board using a microprocessor, a layered model of a printed circuit board for a magnetoelectric current sensor, and also a discussion of possible digital outputs.

2. Principle of Operation

The magnetoelectric current sensor works as follows. When measuring current flows through the current coil, a constant magnetic field H_0 (displacement field) is created. At the input of the solenoid coil, an alternating signal of the generator is applied, which creates an alternating magnetic field $H_\sim$. The alternating magnetic field $H_\sim$ and the permanent magnetic field H_0 are co-directed and perpendicular to the polarization vector P of the piezoelectric composite layer. As a result of the interaction of magnetic and electric fields in the ME element, we observed the transverse magnetoelectric effect. As a result of the transverse magnetoelectric effect, an alternating electrical signal appears, proportional to the strength of the measured current, which is taken from the electrodes.

The sensitive element of the ME sensor is a magnetoelectric composite (Figure 1), made in the form of a piezoelectric plate 1, on whose side of surfaces the plates of Metglas 2 are glued on. The device also includes measuring circuit, consisting of low-frequency signal generator, solenoid coil and current coil. The magnetoelectric element made of composite laminate, for example, the composition Metglas - piezoceramic PZT- Metglas, with a volume fraction v = 0.5.

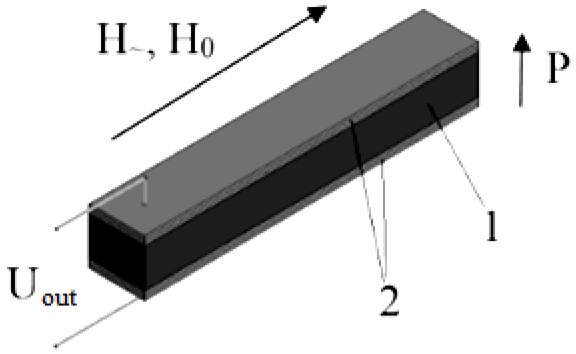

Figure 1. Magnetoelectirc element: 1) piezoceramic plate of PZT; 2) magnetostrictive layers of Metlgas.

Also, the main advantage of the sensor over analogues is the use of the main working mechanism of the magnetoelectric effect. ME composite structures have high sensitivity values, approaching ultra-sensitive and costly SQUID systems, and exceed the sensors of current on the Hall effect in terms of sensitivity.

3. Modeling of the PCB and the case

In Figure 2 the 3D printed circuit board model of ME current sensor is presented. Simulation of the two-layer PCB was made in an Altium Design. In the simulation of PCB, the problems of the optimal position of electronic components and the miniaturization of the sensor were set. The use of modern materials and electronic components can significantly reduce and simplify the sensor PCB. The layered structure of the PCB of the sensor is shown in Figure 3.

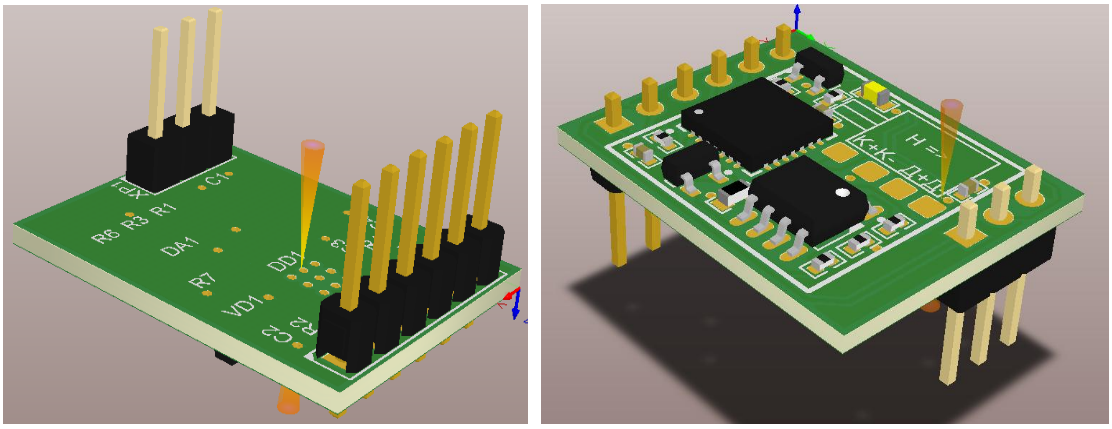

Figure 2. Three-dimensional model of the printed circuit board ME of the current sensor (ME element and coil not shown.

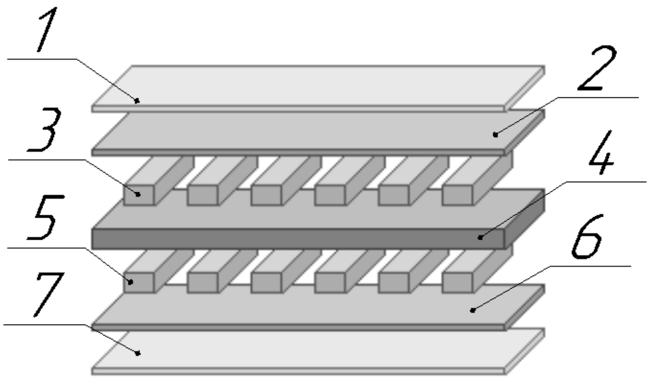

Figure 3. The layered 3D model of the PCB: 1 - Top Overlay, 2 - Top Solder, 3 - Top Layer, 4 - Dielectric, 5 - Bottom Layer, 6 - Bottom Solder, 7 - Bottom Overlay.

Figure 4 shows a three-dimensional model of magnetoelectric current sensor case. Simulation of the case was carried out in CAD Compass 3D V14 and printed on a 3d printer. This case has smaller overall dimensions.

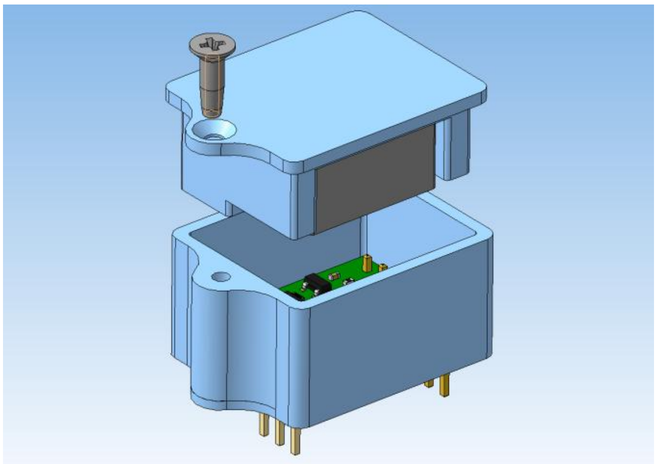

Figure 4. Three-dimensional model of ME sensor current case.

4. Discussion

Microprocessors are indispensable in modern technology and its use at the heart of sensor control is a big advantage. The microprocessor enclosed in a miniature case combines functions of the processor and peripheral devices such as ADCs, comparators, timers, etc., on one chip, and also contains RAM and / or ROM. In fact, it is a single-chip computer capable of performing relatively simple tasks.

Of the many and varied applications of microprocessors, microprocessor systems, object-oriented computing systems, for example, for control, diagnostics, digital signal processing and imaging, occupy one of the first places in terms of volume and use. The microprocessor will work with various interfaces. The following types of interfaces exist: 1-wire; RS-232; RS-485; SPI; I2C; CAN and etc. Each of which has its own peculiarities, advantages and disadvantages. For example, in the 1-wire protocol, only two wires are required to communicate with the device: for data and grounding, the data transmission distance is up to 300 m, the configuration of any 1-Wire network is changing in the process of its operation. Advantages of the RS-232 interface are a large fleet of operating equipment using this standard; simplicity and cheapness of the connecting cable; simplicity and availability of software for working with the interface. The RS-485 interface has the following advantages: convenience of system debugging and simplicity of synchronization of parcels, the possibility of organizing a protocol with direct transmission of binary data and the possibility of being "pure" binary, i.e. without the allocation of special control characters. The SPI protocol has a number of advantages: full-duplex data transfer by default, the ability to arbitrarily select the length of the packet, the length of the packet is not limited to eight bits, the simplicity of the hardware implementation, only four outputs are used, which is much less than for parallel interfaces, the unidirectional nature of the signals allows, if necessary it is easy to organize a galvanic isolation between the master and slave devices, the maximum clock frequency is limited only by the speed of the devices participating in the exchange e data. Among the advantages of the I2C protocol are the following: you need only one microcontroller to manage the set of devices; Use only two conductors to connect multiple devices; simultaneous operation of several master devices connected to the same I2C bus; the standard provides for "hot" connection and disconnection of devices during the operation of the system; A built-in microchip filter suppresses bursts, ensuring data integrity. Car standard CAN has the following advantages: the ability to work in hard real-time mode; simplicity of implementation and minimum costs of use; high resistance to interference; arbitration of access to the network without loss of bandwidth; reliable control of transmission and reception errors; wide range of work speeds.

5. Conclusions

The presented magnetoelectric current sensor is designed for all modern world standards. The sensor is based on the magnetoelectric effect. The sensitive element of the sensor is a magnetostriction-piezoelectric composite structure consisting of the amorphous material Metglas and the plate of piezoceramic PZT-19.

The developed ME sensor PCB using a microcontroller allows the sensor to be used in the variety of modern devices, such as: current monitoring systems, safety systems, etc.

Advantages of such a sensor are: digital output of the device, high sensitivity, low power consumption, small overall dimensions, high linearity of the output characteristic.

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