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Thin Magnetic Film Magnetometer

Anton V. Burmitskikh*, Nikita M. Boev,
Irina A. Negodeeva and Valentina G. Andyuseva
Siberian Federal University
Krasnoyarsk, Russian Federation

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Abstract. This paper presents a novel design of a dual resonator broadband sensor for weak magnetic fields based on thin magnetic films. Such sensors are widely used in various fields, e.g. in geological exploration. The magnetic field of the feedback coil in the sensor is orthogonal to the plane of the printed circuit board with the microwave oscillator. This makes it possible to extend the frequency bandwidth of the measured magnetic fields in the sensors based on thin magnetic films. This is achieved by reducing the effect of the electromagnetic shielding covering the microwave oscillator in the device.

Keywords: magnetic thin films, weak magnetic field sensor, magnetic measurements, magnetometers.

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Тонкопленочный магнитометр

А. В. Бурмитских, Н. М. Боев,
И. А. Негодеева, В. Г. Андюсева
Сибирский федеральный университет
Российская Федерация, Красноярск

Аннотация. В работе представлена новая конструкция двух резонаторного широкополосного датчика слабых магнитных полей на основе тонких магнитных пленок. Магнитные датчики находят широкое применение в различных областях, например при проведении геологоразведочных работ. Магнитное поле катушки обратной связи в разработанном датчике направлено перпендикулярно плоскости печатной платы с СВЧ-генератором. Такая конструкция

* Corresponding author E-mail address: aburmitskikh@iph.krasn.ru

позволяет расширить частотный диапазон измеряемых магнитных полей в датчиках, чувствительным элементом которых являются тонкие магнитные пленки. Увеличение полосы измеряемых частот достигается за счет уменьшения влияния электромагнитного экрана, экранирующего СВЧ-генератор устройства.

Ключевые слова: магнитные тонкие пленки, датчик слабых магнитных полей, магнитные измерения, магнитометры.

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Introduction

Sensors for measuring weak magnetic fields are widely used for the variety of tasks in science, research and technology, including exploration work to investigate the structure of the Earth structure [1].

Currently, there are many types of sensors designed to measure weak magnetic fields, each tailored to solve specific scientific and technical problems. Classifying all types of magnetic sensors is a complex problem, but generally, they can be categorized into the following groups. For example, they can be classified based on the range of measured magnetic field magnitude and their ability to measure magnetic fields across a wide frequency bands (Fig. 1). Additionally, it is important to consider the size of the sensor for most practical applications.

It should be noted that, for example, electrical exploration with artificial excitation of the medium requires a frequency of several thousand kilohertz. Therefore, one of the most important requirements for sensors is wide bandwidth of the measured frequencies and low level of self-noise. Sensors for weak magnetic fields based on thin magnetic films are often used to solve such problems [2].

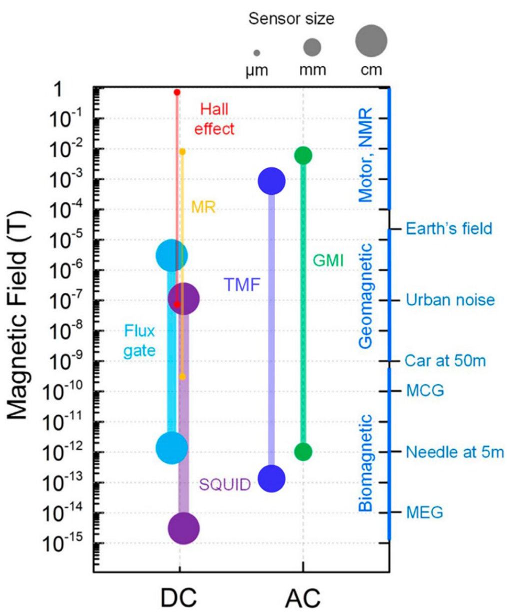

Fig. 1. Comparison of the measurement range of magnetic field sensors [2]

Data and methods

Thin magnetic film magnetometer consists of two microwave oscillators, two resonators with two thin magnetic films, amplitude detectors, a signal combiner, a magnetic system, a measurement compensation system [3]. Thin magnetic films are obtained by magnetron sputtering of the Permalloy ($Ni_{80}Fe_{20}$). The microwave oscillator of the sensor was developed on the basis of a colpitts oscillator circuit [4]. The amplitude detectors of this sensor operate in signal doubling mode. The compensation measuring circuit of the sensor contains a signal repeater (buffer stage) based on an operational amplifier. Unwanted compensation signals from the sensor are suppressed by a low-pass filter. The sensor compensation magnetic field is generated by a multi-part compensation coil wound on a plastic frame.

The basic elements of the broadband sensor are located on dual printed circuit boards (Fig. 2).

The first PCB of the sensor (Fig. 2*a*) is fitted with electronic components on both sides. The oscillators, detectors, and tuning elements are located on the top side of the board. The high-pass filter and the signal adder are located on the bottom side. The second circuit board (Fig. 2*b*) contains two microwave resonators based on a microstrip transmission line (MTL). The thin magnetic films are located under the MTL. The resonant frequency of the circuit is tuned using trimming capacitors and lumped elements (inductors). The microwave oscillator of the sensor is exposed to external electromagnetic fields. This affect is minimized by electromagnetic shielding of the oscillator.

The shielding covers the microwave area of the PCB (Fig. 2*a*) and is soldered along the PCB contour. The compensation magnetic field around the thin magnetic films inside the resonator is generated by the compensation coil of the sensor. If the electromagnetic shielding is on the same axis as the coil axis, the generated magnetic field is "isolated" by the shielding. This "isolate" is reduced by connecting the PCBs perpendicular to each other. The electrical contact between the PCBs is established through the via-holes. The design of the sensor with spaced parts is shown in Fig. 3. The electrical contact between the PCBs is established through metallized via-holes in the circuit board (Fig. 2*b*). The circuit board (Fig. 3) is located in the center of the compensation coil.

The weak magnetic field sensor was developed and calibrated. An experimental unit for measuring the self-noise level of the sensor was designed. A three-layer magnetic shield made of permalloy was placed inside the shielded room. The sensor under test was positioned within the electromagnetic shield. The sensor was connected to accumulator batteries. The signal from the sensor's output was fed

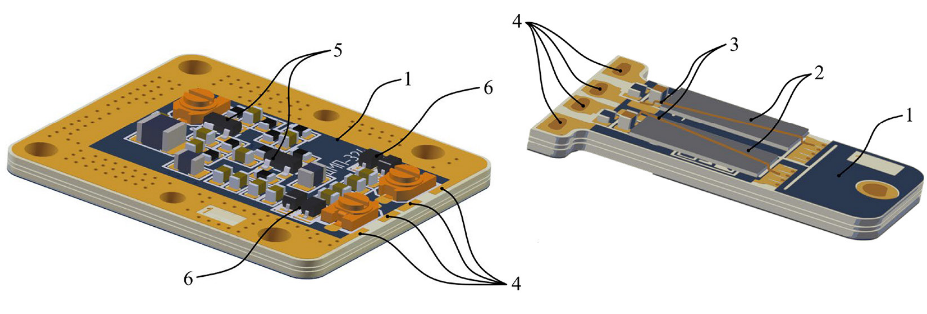

Fig. 2. PCB of microwave oscillator (*a*) and resonator (*b*) (1 – PCB; 2 – thin magnetic films; 3 – microstrip transmission line; 4 – via-holes; 5 – microwave oscillator; 6 – amplitude detector)

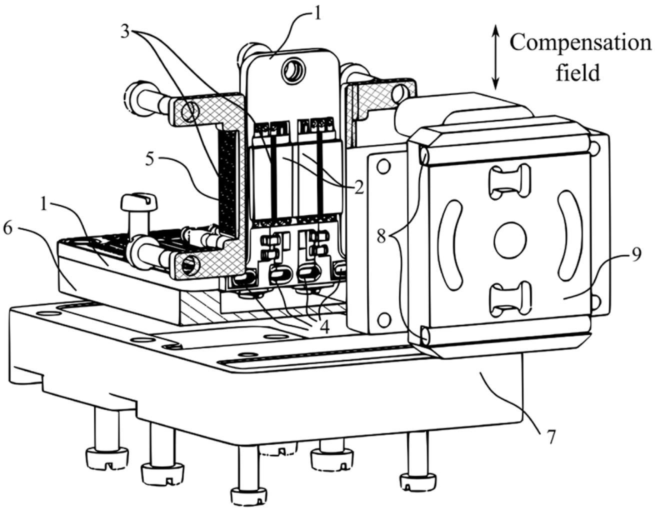

Fig. 3. Weak magnetic field sensor design (1 – PCB; 2 – thin magnetic films; 3 – microstrip transmission line; 4 – via-holes; 5 – compensation coil; 6 – electromagnetic shield; 7 – device enclosure; 8 – magnets; 9 – holder)

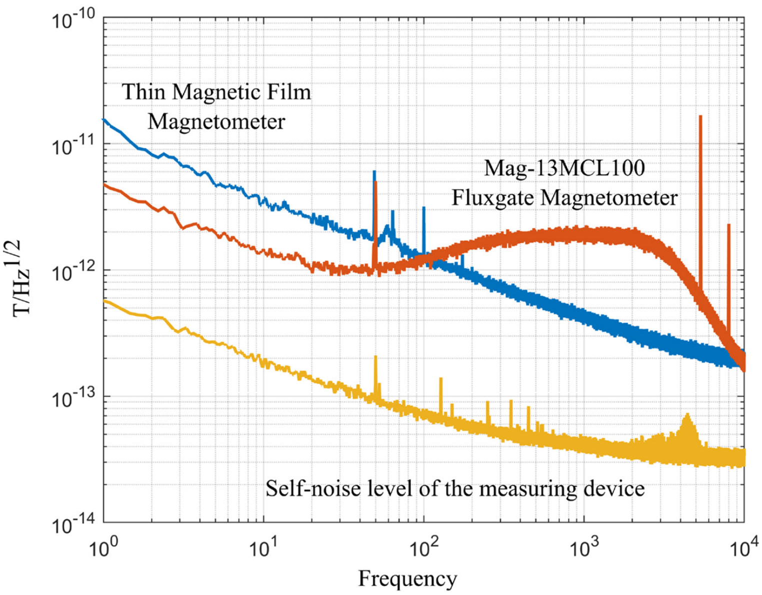

Fig. 4. Self-noise level of the device

into the input of an R&S UPV low-frequency audio analyzer. Before taking measurements, the self-noise levels of the measuring instrument and the noise level of the Bartington Mag-13MCL100 fluxgate were measured (Fig. 4).

Conclusion

As shown in the Fig. 4, at a frequency of 1 Hz, the spectral density of the self-noise amplitude does not exceed 20 pT/√Hz. At frequencies above 10 kHz, the noise level becomes constant at 0.2 pT/√Hz. The upper limit frequency of the sensor, measured using high-frequency Helmholtz coils is 1.1 MHz.

Within the operating frequency range from 0.1 Hz to 1 MHz, the device has a constant conversion factor of 10 V/Oe.

Experimental investigations (measurement results) show that the magnetic isolation in compensation coil decreases, so that the frequency range of the device could be extended. This makes it possible to carry out measurements of magnetic fields in the frequency range up to 6 MHz.

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