SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 15, No. 2, June 2018, 225-232

UDC: 681.586.7:621.317.31]:005.9 **DOI: https://doi.org/10.2298/SJEE1802225J**

Low-cost Teslameter based on Hall Effect Sensor MLX90242

Uglješa Jovanović[1], Igor Jovanović[1], Marjan Blagojević[2], Dejan Krstić[3], Dragan Mančić[1]

Abstract: A low-cost teslameter based on a Hall effect sensor MLX90242 is proposed in this paper. The proposed teslameter is built around a PIC18F4550 microcontroller and it can measure magnetic flux density in the range between –55 mT and 55 mT. Temperature stability of measurements originates from the MLX90242 sensor itself. In order for the proposed transducer to be accurate, it has undergone a calibration procedure using a highly accurate teslameter employed as reference instruments and high-quality variable-field electromagnet. The proposed teslameter can store measurements on a PC via built-in USB communication.

Keywords: Calibration, Hall effect sensor, Microcontroller, Teslameter, Variable-field electromagnet.

1 Introduction

Magnetic fields can be visualized as magnetic flux lines. Magnetic flux density is measured by teslameters or gaussmeters. In its simplest form, a teslameter consists of a magnetic field probe and an electronic processing circuit. The magnetic field probe converts a measured magnetic flux density into an electrical signal i.e. voltage. Thanks to their growing accuracy and very low prices, Hall effect sensors became a preferred selection for magnetic field probes [1]. In addition to this, Hall effect sensors have many other applications such as accurate electric current measurement [2, 3].

In nowadays several vendors provide numerous commercially available teslameters. However, even the basic versions are quite expensive and their prices begin around 500$. Moreover, highly accurate teslameters have prices starting from 3,000$ [4] and 10,000$ [5].

A cost-effective solution is to realize a relatively simple custom-made teslameter using an inexpensive commercially available components. If the

[1]University of Niš, Faculty of Electronic Engineering Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia;
E-mails: ugljesa.jovanovic@elfak.ni.ac.rs, igor.jovanovic@elfak.ni.ac.rs, dragan.mancic@elfak.ni.ac.rs
[2]IRC Sentronis AD, Knjaževačka 38, 18000 Niš, Serbia; E-mail: marjan@sentronis.rs
[3]University of Niš, Faculty of Occupational Safety in Niš, Čarnojevića 10a, 18000 Niš,
E-mail: dejan.krstic@znrfak.ni.ac.rs

production costs are to be minimal, a teslameter can be realized without temperature compensation [6, 7] otherwise it can be implemented as presented in the literature [8]. Although such teslameters can be realized for a fraction of the costs of commercial teslameters they usually have a lower measurement accuracy though not necessarily significantly lower.

This paper presents a simple, yet accurate, low-cost teslameter based on a MLX90242 Hall effect sensor [9]. The proposed teslameter is capable of measuring magnetic flux density in the range between –55 mT and 55 mT with the accuracy better than ±0.2% and good temperature stability. The costs of the proposed teslameter are in the region of 15$, which a fraction of the costs of commercially available teslameters with similar characteristics.

2 System Design

A magnetic field probe of the proposed teslameter is based on a Hall effect sensor MLX90242. According to the specifications, this sensor has an active error correction circuitry, which almost eliminates offset errors normally associated with Hall effect sensors [10]. Much like many other Hall effect sensors, the MLX90242 has ratiometric output voltage, which means that the output voltage is at half of the power supply voltage when a zero magnetic flux density is applied.

The proposed teslameter consists of the MLX90242 Hall effect sensor connected via 1 m long shielded cable to the PCB containing the PIC18F4550 microcontroller (MCU), the COG LCD display and the power supply circuit. Photo of the proposed teslameter is shown in Fig. 1.

The output voltage of the MLX90242 is fed into the built-in 10-bit ADC of the MCU. Based on this voltage, the MCU calculates magnetic flux density using the following expression:

$$B = \frac{V_{OUT} - 2.5\ \text{V}}{S}, \tag{1}$$

wherein V_{OUT} is MLX90242 output voltage in [V], S is its sensitivity to a magnetic field change in [mV/mT] and 2.5 V is the MLX90242 output voltage when zero magnetic flux density is applied.

After the MCU calculates magnetic flux density using (1) it displays this value on the 16×2 COG LCD display. Additionally, at the end of each measurement cycle, the MCU forwards measurement result to a PC via built-in HID USB communication. The custom-made virtual instrument, installed on the PC, handles the acquisition of measurements, their visualization and storage.

Fig. 1 – *Photo of the proposed teslameter.*

3 Calibration Procedure

A major issue with the MLX90242 is the fact that its sensitivity is specified in a wide range, which makes it impossible to conduct accurate magnetic flux density measurements. To be more precise, sensitivity of the MLX90242 varies on a piece to piece basis in the range between 33.2 mV/mT and 44.9 mV/mT [10]. Consequently, the measurement range of the proposed teslameter could then be either ±75 mT or ±55 mT depending on the sensitivity. To resolve this issue properly and to determine the exact MLX90242 sensitivity, the proposed teslameter had to be calibrated.

Calibration of the proposed teslameter is conducted by subjecting the MLX90242 to a variable magnetic field in the range between –80 mT and 80 mT. In accordance to that, the MLX90242 is inserted into a variable-field electromagnet made by Bruker (see Fig. 2). Reference magnetic flux density measurements are recorded using a highly accurate teslameter Senis 3MH3A [11], which has accuracy better than ±0.05% compared to a nuclear magnetic resonance teslameter (NMR) Metrolab PT2025. During the calibration the MLX90242 output voltage is measured using an Agilent 34401A voltmeter. Photo of the measurement setup is shown in Fig. 2, wherein on the left side is the MLX90242 and on the right is the integrated probe of the Senis 3MH3A teslameter.

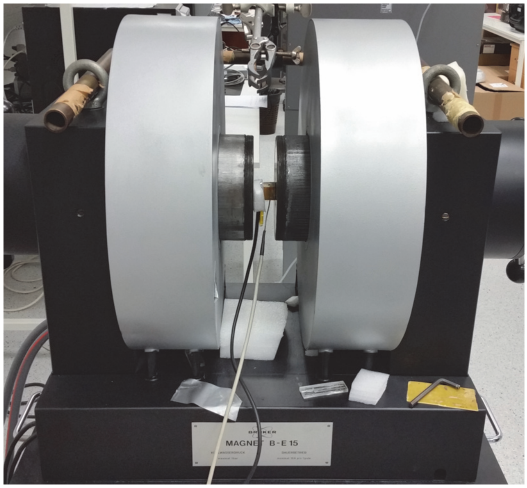

Fig. 2 – *Calibration of the proposed teslameter.*

During the calibration it was noted that the MLX90242 is saturated when magnetic flux density exceeds ±55 mT. Consequently 12 measurements are recorded in the range between -55 mT and 55 mT. Additionally, a zero flux measurement is performed by inserting the MLX90242 into a zero gauss tube. Measurement results of this experiment conducted at 25°C are shown in Fig. 3.

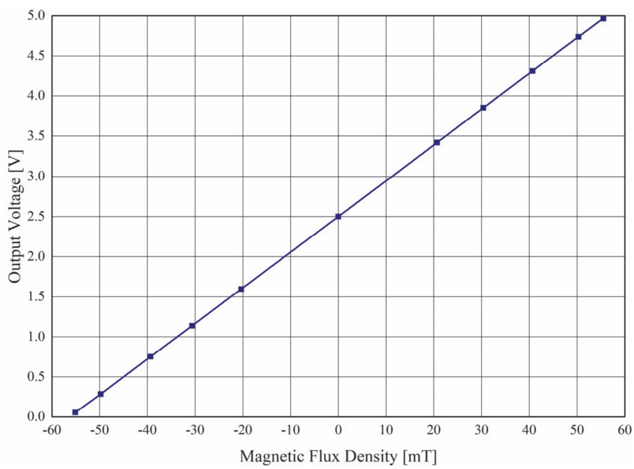

Fig. 3 – *Calibration results.*

By analyzing the obtained measurements shown in Fig. 3, it is obvious that the MLX90242 has excellent linearity. Sensitivity of the employed sensor is calculated to be 44.45 mV/mT, which is only slightly lower than the maximal specified sensitivity value but considerably higher than the minimal value.

Upon inserting the proper MLX90242 sensitivity into (1), the measurement accuracy of the proposed teslameter was evaluated by comparing its measurements with corresponding measurements taken by the Senis 3MH3A teslameter. The results of this experiment are shown in **Table 1**.

Table 1

Measurement accuracy of the proposed teslameter.

Mag. flux den. [mT]	–50	–40	–30	–20	0	20	30	40	50
Relative error [%]	–0.11	–0.04	–0.16	–0.17	0	0.12	0.02	0.006	–0.007

As can be seen from **Table 1**, accuracy of the proposed teslameter is better than ±0.2% compared to the Senis 3MH3A teslameter, which represents an excellent result considering the fact that the proposed transducer does not employ a linearization circuit. For instance, all integrated magnetic field probes of the Senis 3MH3A teslameter have certain differences which are compensated with the linearization circuit. By employing a proper linearization circuit, the measurement accuracy of the Senis 3MH3A teslameter is kept well within the specified ±0.05% in the entire measurement range, which can be easily seen in the measurements recorded at 22.5°C presented in **Table 2**.

Table 2

Measurement accuracy of the Senis 3MH3A.

Mag. flux den. [mT]	–200	–145	–100	–45	0	56	101	147	200
Relative error [%]	–0.004	0.005	0.002	0.002	0	0.002	0.009	-0.006	0.002

A second major issue with the MLX90242 is its temperature coefficient which is, much like its sensitivity, not precisely specified. Namely, the temperature coefficient of the MLX90242 is between 430 ppm/ºC and 930 ppm/ºC [10]. Although this range is pretty wide, the values are quite good for a low-cost teslameter. In order to determine the temperature coefficient of the MLX90242 it is necessary to conduct temperature stability evaluation.

Temperature stability of the proposed teslameter is evaluated by subjecting the MLX90242 to wide temperature range by inserting the MLX90242 into a TestEquity Model 115A temperature chamber in which the temperature is gradually increased from –20ºC up to 80ºC while the MLX90242 output voltage is measured using the Agilent 34401A voltmeter. During this experiment 10 measurements are taken with a 10 minutes pause between them so the measurements could settle. It should be noted that during these measurements the MLX90242 was inserted into the zero gauss tube, hence there was no impact from stray magnetic fields. Measurement results of this experiment are shown in Fig. 4.

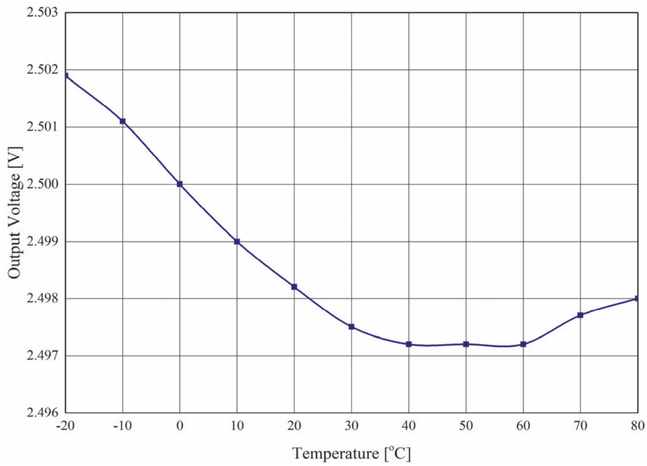

Fig. 4 – *Temperature stability of the proposed teslameter.*

As can be seen from Fig. 4, temperature stability of the proposed teslameter is far better in case of temperatures higher than 20ºC compared to lower temperatures. The difference between the maximal and minimal MLX90242 output voltage is less than 5 mV, which is less than 0.11 mT. For instance, uncompensated integrated magnetic field probes of the Senis 3MH3A teslameter have roughly two times better temperature coefficient in the range between 15°C and 35°C, which is in fact the most commonly used temperature range. This can be seen from the temperature stability graph presented in Fig. 5.

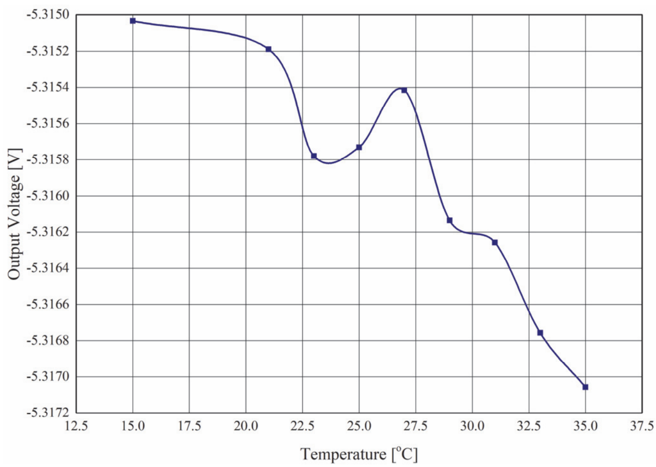

Fig. 5 – *Temperature stability of the Senis 3MH3A.*

Based on Figs. 4 and 5 it was concluded that the temperature coefficient of the proposed teslameter is perfectly acceptable hence no temperature compensation is implemented.

4 Conclusion

The digital low-cost teslameter based on the MLX90242 Hall effect sensor has been designed and realized. The costs of the proposed teslameter are in the region of 15$ but they can be additionally reduced and it can measure magnetic flux density in the range between –55 mT and 55 mT.

Unspecified sensitivity of the MLX90242 posed a major issue because it could produce a huge measurement error. To address this issue properly, the proposed teslameter was calibrated using the high-quality variable-field electromagnet made by Bruker and the Senis 3MH3A teslameter employed as the reference instrument. After the calibration was successfully performed the maximal relative measurement error recorded in the entire measurement range was less than ±0.2% compared to the corresponding measurements taken by the Senis 3MH3A teslameter.

Temperature stability of the proposed teslameter was evaluated by subjecting the MLX90242 to a much wider temperature range than in case of the normal operating conditions. During this experiment, it was observed that temperature stability is far better for temperatures higher than 20ºC compared to lower temperatures. Since the temperature stability of the proposed teslameter was perfectly acceptable no temperature compensation circuit was employed.

It should be noted that the measurement accuracy of the proposed teslameter could be additionally improved by employing a proper linearization circuit and temperature compensation circuit.

Research presented in this paper has shown how a simple and accurate low-cost teslameter can be realized using only a few off-the-shelf low-cost components.

5 Acknowledgment

The research presented in this paper is financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia under the project III43014.

6 References

[1] R.S. Popović: Hall Effect Devices, 2nd ed., IOP Publishing Bristol and Philadelphia, 2004.

[2] M. Blagojević, U. Jovanović, I, Jovanović, D. Mančić, R.S. Popović: Realization and Optimization of Bus Bar Current Transducers Based on Hall Effect Sensors, Measurement Science Technology, Vol. 27, No. 6, 2016, p. 065102.

[3] M. Blagojević, U. Jovanović, I, Jovanović, D. Mančić: Folded Bus Bar Current Transducer Based On Hall Effect Sensor, Electrical Engineering, Vol. 100. No.2, 2018.

[4] D. R. Popović, S. Dimitrijević, M. Blagojević, P. Kejik, E. Schurig, R. S. Popović: Three-axis Teslameter with Integrated Hall Probe, IEEE Transactions on Instrumentation and Measurement, Vol. 56, No. 4, 2007, pp. 1396 – 1402.

[5] D. Popović Renella, S. Dimitrijević, S. Spasić, R.S. Popović: High-accuracy Teslameter with Thin High-Resolution Three-Axis Hall Probe, Measurement, Vol. 98, 2017, pp. 407 – 413.

[6] K. Atkin: Construction of a Simple Low-Cost Teslameter and its Use with Arduino and MakerPlot Software, Physics Education, Vol. 51, 2016, p. 024001.

[7] G. Torzo, A. Sconza, R. Storti: A Low-Cost Digital Teslameter, Journal of Physics E: Scientific Instruments, Vol. 20, 1987, pp. 260 – 262.

[8] K. R. Dickson, P. Galbraith: A Digital Micro-Teslameter, Cern, European Organization for Nuclear Research, 1985.

[9] U. Jovanović, I. Jovanović, M. Blagojević, D. Mančić: One Solution of a Low-Cost Teslameter, 13th International Conference on Applied Electromagnetics - ПЕС 2017, 30 August– 1 September 2017, Niš, p. O5.

[10] Melexis: MLX90242 Linear Hall Effect Sensor Data Sheet, 2012.

[11] Senis AG: 3MH3A Magnetic Field Digital Teslameter, 2013.