One Solution of a Low-Cost Teslameter

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ONE SOLUTION OF A LOW-COST TESLAMETER

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Abstract: This paper presents a very simple low-cost teslameter based on a Hall effect sensor MLX90242 and built around a PIC18F4550 micro-controller. The proposed teslameter is capable of measuring magnetic flux density up to ±55 mT with a good temperature stability provided by the MLX90242 itself. In order to increase the measurement accuracy, the proposed teslameter undergone a calibration procedure with a highly accurate teslameter and nuclear magnetic resonance precision teslameter employed as a reference instruments. The proposed teslameter can send its measurements to a computer via built-in USB communication.

Keywords: Calibration, Hall effect sensor, Microcontroller, Nuclear magnetic resonance, Teslameter.

INTRODUCTION

Magnetic flux density is measured by a device called teslameter. Usually, a teslameter is consisted of a magnetic field probe and an electronic processing circuit. The probe converts measured magnetic flux density into an electrical signal. Nowadays, most teslameter probes are based on a Hall effect sensors due to their low prices and growing accuracy [1]. Thanks to their versatileness, Hall effect sensors can also be used for electric current measurement application as suggested in papers [2-4].

Digital teslameters include analogue-to-digital conversion (ADC) in a signal processing. Usually a user interface includes a display or/and communication with a personal computer (PC).

Although there are a great deal of commercially available teslameters, even the simplest versions are quite expensive. Usually their starting price tags are around 500$. Highly accurate teslameters have prices starting from 3000$ [5] or even 10 000$ [6].

If a measurement accuracy is not a crucial factor, a cost effective solution can be to realize a relatively simple custom-made teslameter based on an inexpensive commercially available components without implementation of temperature compensation [7, 8]. If, however, temperature compensation is necessary, it can be implemented in a way presented in paper [9]. Such teslameters can be realized for a fraction of the costs of branded teslameters.

This paper presents a simple low-cost teslameter based on a MLX90242 Hall effect sensor. The proposed teslameter is capable of measuring magnetic flux density up to ±55 mT with an excellent accuracy of 0.2% and a good temperature stability. It should be noted that the costs of the proposed transducer are less than 15-20$, which represents a fraction of the costs of commercially available teslameters.

SYSTEM DESIGN

According to the vendor, the MLX90242 has an active error correction circuitry, which almost eliminates offset errors normally associated with Hall effect sensors [10]. The ratiometric output voltage is set by the supply voltage, which means that when no magnetic field is applied the output will be at half of the power supply voltage, i.e. 2.5 V when a 5 V power supply is applied.

The proposed teslameter is quite simple. It consists of the MLX90242 Hall effect sensor, the PCB with the PIC18F4550 microcontroller (MCU), the COG LCD display and the power supply circuit. The PCB is enclosed in the aluminium box in order to minimize impact of the external noise. Block diagram of the proposed teslameter is shown in Fig. 1.

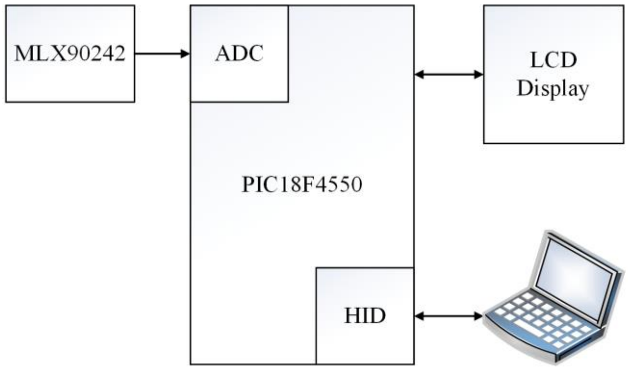

Fig.1 - *Block diagram of the proposed teslameter.*

The MLX90242 requires just two capacitors and a single resistor in order to be connected in an electric circuit, as can be seen in Fig. 2.

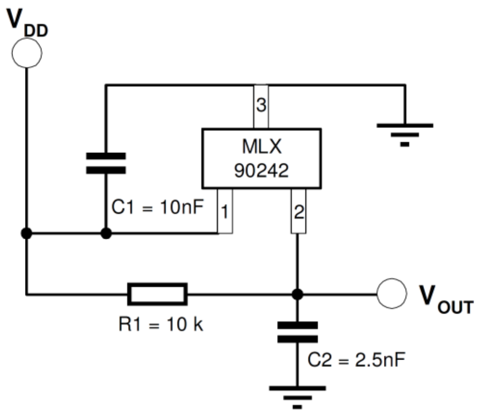

Fig.2 - *Electric circuit around the MLX90242. [10]*

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As can be seen in Fig. 1, 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 simple following expression:

$$B = \frac{V_{OUT} - 2.5\,V}{S} \quad (1)$$

wherein V_{OUT} is the MLX90242 output voltage in [V], S is its sensitivity to a magnetic field in [mV/mT] and 2.5 V is the MLX90242 output voltage when no magnetic field is applied.

After the magnetic flux density is calculated, its value is displayed on the 16x2 COG LCD display. COG display is selected primarily because of its low power consumption. At the end of each measurement cycle, the MCU forwards measurement result to a PC via built-in HID USB communication. Custom-made virtual instrument, installed on the PC, handles data acquisition and storage on a HDD. Photo of the proposed teslameter is shown in Fig. 3.

Fig.3 - *Photo of the proposed teslameter.*

The MLX90242 is connected by 2 m long shielded cable to the PCB containing the electronic circuitry.

The suitable virtual instrument for the data acquisition is developed in LabVIEW. Print screen of the virtual instrument front panel while the system is not running is shown in Fig. 4.

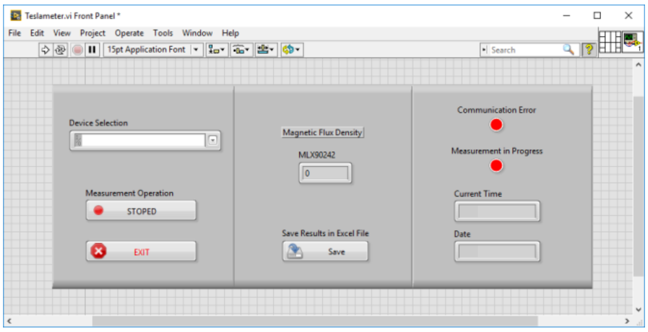

Fig.4 – *Print screen of the virtual instrument front panel.*

CALIBRATION PROCEDURE

A calibration procedure using a high-stability electromagnet and a highly accurate reference instrument allows the Hall voltage to be converted directly to units of magnetic flux density. Furthermore, the calibration procedure can improve measurement accuracy mainly because a user does not must relay on data sheet specifications which are usually general and have a wide range.

Sensitivity of the MLX90242 is not precisely specified, which makes accurate magnetic flux density measurement almost impossible. Namely, according to the vendor, sensitivity is between 33.2 mV/mT and 44.9 mV/mT [10], hence the measurement error can be as much as 20 mT, which is quite substantial considering that the measurement range could then be either 75 mT or 55 mT depending on the sensitivity. To resolve this issue adequately, the proposed teslameter undergone a thorough calibration procedure.

Calibation of the proposed system is conducted by subjecting the MLX90242 to an adjustable magnetic field in the range of ±55 mT. This is performed by inserting the MLX90242 into an adjustable electromagnet made by Bruker (see Fig. 5). Reference measurements are taken by a highly accurate teslameter Senis 3MH3A [11], which has accuracy better than 0.01% in the measurement range of ±200 mT compared to a nuclear magnetic resonance teslameter (NMR) Metrolab PT2025. The MLX90242 output voltage is measured using an Agilent 34401A voltmeter. The main reason the proposed teslameter is not calibrated only using the NMR Metrolab PT2025 lies in the fact that minimal magnetic field it can detect is 45 mT. However, it should be noted that measurements above ±45 mT have been verified using the NMR Metrolab PT2025.

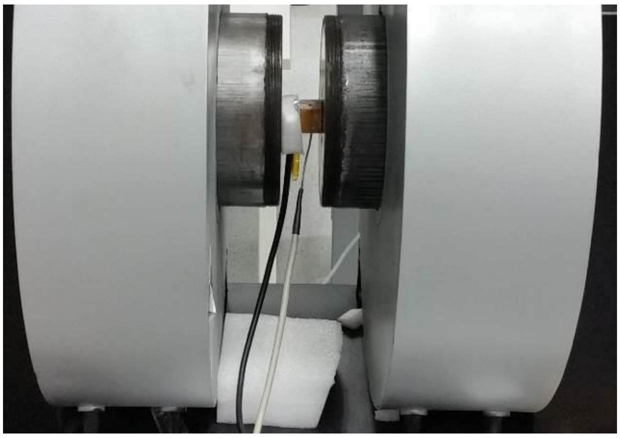

Fig.5 - *Calibration of the proposed teslameter.*

Five calibration points are taken for negative fields from -55 mT to -20 mT and five points for positive fields from 20 mT to 55 mT. A 0 mT MLX90242 output voltage is obtained by inserting the MLX90242 into a zero gauss tube and measuring its output voltage using the Agilent 34401A. Measurement results obtained during the calibration procedure are shown in Fig. 6.

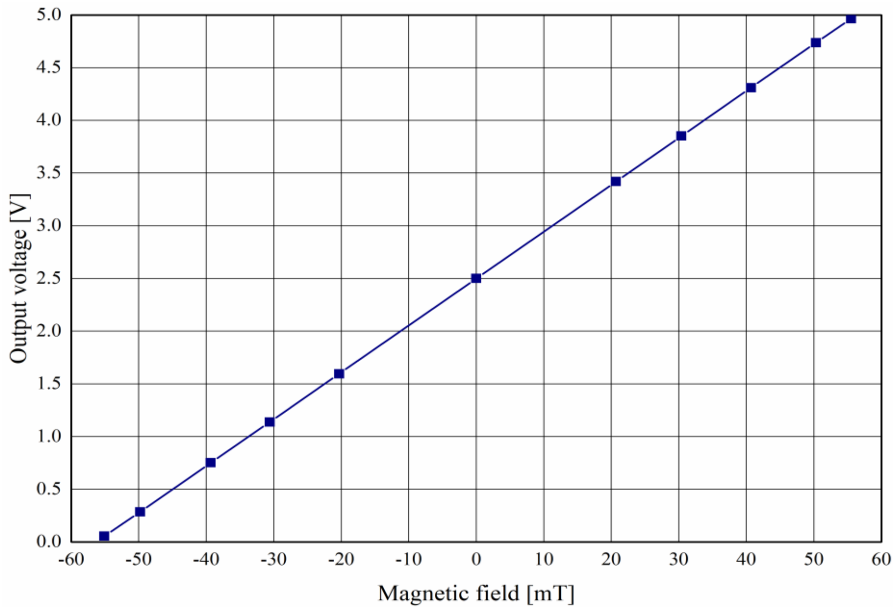

Fig.6 - *Calibration results.*

Based on the obtained measurements shown in Fig. 6, it can be concluded that the MLX90242 is pretty linear and its sensitivity is calculated to be 44.45 mv/mT, which is slightly lower than the maximal specified sensitivity but considerably higher than the minimal.

After inserting the proper MLX90242 sensitivity value into Eqn. (1), calculated by the MCU, the measurement accuracy of the proposed teslameter was evaluated exactly in the same way the calibration procedure was performed. During the evaluation, the maximal recorded relative error between the corresponding measurements taken by the proposed teslameter and the Senis 3MH3A teslameter was less than ±0.2%, which is excellent for a low-cost teslameter.

Much like the sensitivity, the temperature coefficient of the MLX90242 is also not precisely specified. According to the vendor temperature coefficient is between 430 ppm/ºC and 930 ppm/ºC [10], which is a pretty wide range.

Temperature stability is verified by subjecting the MLX90242 to a wide temperature range. This is performed by inserting the MLX90242 into a TestEquity Model 115A temperature chamber in which the temperature was gradually increased starting from -20ºC up to 80ºC. Exactly 10 calibration points are taken for the entire temperature range. Measurement results of this experiment are shown in Fig. 7.

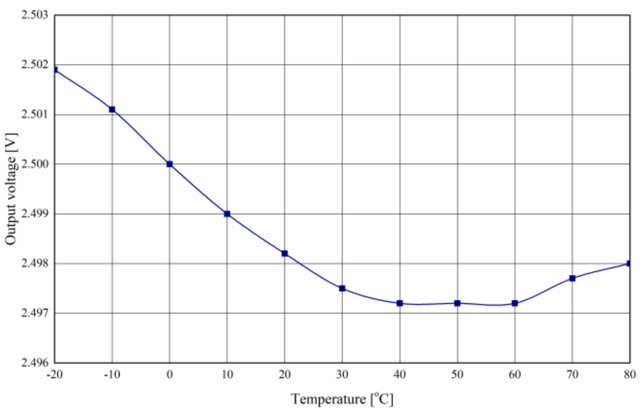

Fig.7 - *Temperature stability results.*

As can be seen from Fig. 7, temperature stability is far better for temperatures above 20ºC than for lower temperatures. Moreover, the difference between output voltages at 20ºC and -20ºC is less than 4 mV which is effectively 0.09 mT for the entire temperature range or 0.00225 mT/ºC.

CONCLUSION

A digital low-cost teslameter based on the MLX90242 Hall effect sensor has been designed and realised. The proposed teslameter is capable of measuring magnetic field flux in the range between -55 mT and 55 mT.

Sensitivity of the MLX90242 is not precisely specified, which can produce a considerable measurement error. Therefore, the proposed teslameter had to undergone the calibration procedure using the adjustable electromagnet and the Senis 3MH3A teslameter and NMR Metrolab PT2025 as reference instruments. The obtained measurement results have shown that the relative measurement error is less than ±0.2% compared to the corresponding measurements taken by the reference Senis 3MH3A.

Temperature compensation has not been implemented, never the less temperature stability has been evaluated by subjecting the MLX90242 to a wide temperature range. During this evaluation, it was observed that temperature stability is far better for temperature above 20ºC in contrast to lower temperatures where the measured magnetic flux density drops at the rate of 0.00225 mT/ºC.

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

ACKNOWLEGMENT

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