DC Digital Gaussmeter Based on Linear Hall-Effect Sensor IC

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***Abstract*—In this paper, a DC digital gaussmeter for measuring magnetic fields up to ±1000 G (±100 mT) is presented. It consists of two interchangeable transverse magnetic field probes based on Hall-effect sensor integrated circuits (ICs), a data acquisition module developed around a 8-bit PIC18F4550 microcontroller, a standard 2x16 character LCD display and a 5 V power supply module operating from 6 AA batteries. The instrument features USB connectivity and LabVIEW software for PC remote control. The gaussmeter is suitable for a full range of DC magnetic field measurements, and can be used for both research and teaching activities.**

***Keywords*—DC magnetic field; digital gaussmeter; Hall-effect sensor IC; USB connectivity**

I. Introduction

A gaussmeter is an instrument for measuring magnetic flux density, B, at a given point in space [1]. Currently, many gaussmeters employ Hall-effect sensor elements as magnetic field probes [2-4]. In its simplest form, a gaussmeter consists of a linear Hall-effect sensor connected to a readout device, e.g. a digital multimeter (DMM). Indeed, it is possible to build a simple gaussmeter from a calibrated linear Hall-effect sensor IC, a few passive components and a DMM, but the result would provide only limited functionality. A more flexible and yet economical solution is to integrate a Hall-effect sensor IC with a microcontroller unit, thus implementing a standalone instrument. In addition to a front panel display, such a gasussmeter can also communicate with a PC.

By using the Hall effect in a fully integrated monolithic IC, it is possible to measure magnetic flux density and create a large array of Hall-effect ICs for different applications. In comparison to other devices for magnetic field sensing, the Hall-effect sensor ICs present advantages such as low cost, small dimensions, wide measurement range and low power consumption. They also present a very high electric field rejection during the measurements and can detect the polarity of the measured magnetic field. Mostly, the Hall-effect sensor ICs have a linear transfer characteristic, the output voltage being directly proportional to the incident magnetic flux density. When no field is applied, the output voltage is nominally $V_{CC}/2$. In the presence of a south pole, the output voltage will move in the direction of V_{CC}, while in the presence of a north pole, the output voltage will move in the direction of *GND*. It is important to note that large magnetic fields will not damage the Hall-effect sensor ICs, but rather drive them into saturation [5-7].

Taking into account these issues, our paper proposes a digital gaussmeter based on Hall-effect sensor IC, which is provided with two transverse probes capable of measuring DC magnetic fields in the ranges of ±1000 G (±100 mT) and ±500 G (±50 mT), respectively. Designed as an affordable solution for carrying out DC magnetic field measurements, the developed DC gaussmeter provides ease of use, portability and multiple functionality, including probe selection, switchable units (millitesla and gauss), determination of the magnetic field polarity and PC remote operation via the USB interface, using intuitive LabVIEW application software.

II. Principle of Operation

The simplified block diagram of the DC digital gaussmeter is presented in Fig. 1. The operation of the instrument is controlled by a renowned 8-bit PIC18F4550 microcontroller from Microchip Technology [8], which integrates a 10-bit analog-to-digital converter (ADC) and a Full Speed USB 2.0 (12 Mbit/s) interface, and which is ideal for low power (nanoWatt technology) applications.

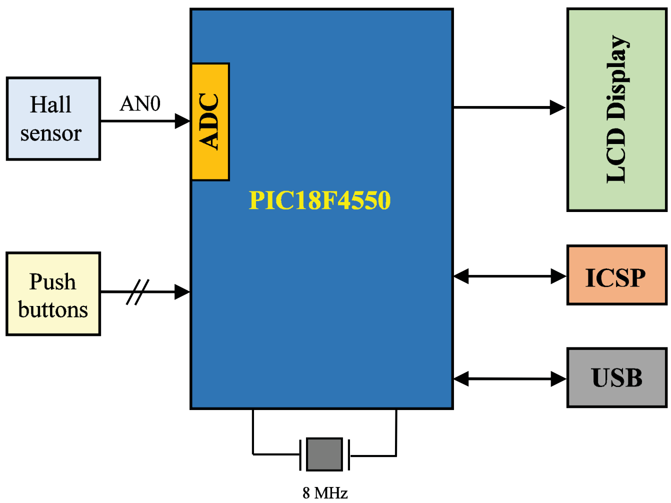

Fig. 1. Simplified block diagram of the DC digital gaussmeter.

The DC output voltage of the used Hall-effect sensor IC – proportional to the measured magnetic flux density – is applied to the analogic input AN0 (pin 2) of the microcontroller, with the 5 V reference voltage for ADC derived from V_{CC}. An external voltage reference of 1.024 V is also included in design for further developments. The 2x16 character LCD display is connected to the port B of the microcontroller, by using the 4-bit interfacing mode. The microcontroller operates from an 8 MHz external oscillator, but the clock frequency is raised to 48 MHz by the internal PLL (Phase Locked Loop) circuitry of PIC18F4550. A 5-pin ICSP (In-Circuit Serial Programming) connector offers a convenient way of programming the microcontroller without removing the chip from the target board. Two push buttons are connected to the port D of the microcontroller, allowing user to change the measurement unit and activate the polarity detection function. The microcontroller, sensor and LCD display operate from a single 5 V supply voltage, obtained from six AA batteries, through the use of 7805 voltage regulator (not shown in Fig. 1).

The firmware residing in the microcontroller flash memory is written in *mikroC for PIC* compiler and allows either standalone or PC remote operation. In the last case, the instrument connects to the PC via a simple USB cable. The associated PC software was developed in the LabVIEW graphical programming environment [9-11], as already mentioned, and makes use of NI-VISA (National Instruments implementation of the Virtual Instrumentation Software Architecture industry standard) [12], which allows communicating with the instrument via the USB interface.

III. Instrument Design

The gaussmeter (called DC-HG1) was mainly designed as a hand-held, battery-operated instrument. It consists of several electronic modules, interconnected and integrated into an ABS enclosure. Details regarding instrument design and assembly are given in the following.

A. *Magnetic field probes*

The two developed magnetic fields probes are based on the Allegro A1326/24 ratiometric Hall effect sensor ICs, both available in a 3-pin SIP package (Fig. 2). The A1326/24 feature factory programmed sensitivities of 2.5 mV/G and 5.0 mV/G, respectively. They operate over a wide ambient temperature range (–40°C to 150°C), providing a null voltage drift, in terms of magnetic flux density, of only ±10 G and a sensitivity temperature coefficient, calculated relative to the sensitivity at 25 ºC, of ±0.03 %/ºC. Their output referred noise is also low: 3.5 mV_{pp} and 7 mV_{pp}, respectively [13].

Fig. 2. A1326/24 low noise, linear Hall-effect sensor ICs with analog output, 3-pin ultramini SIP (1.5 mm x 4 mm x 3 mm).

The electric scheme of the magnetic field probes in shown in Fig. 3, were the two capacitors of 100 nF are used for noise suppression. In order to minimize the influence of the AC magnetic fields (the specified 3-dB bandwidth of the A1326/24 sensor ICs is 17 kHz), a simple low-pass filter can be inserted at the probe output, but, in most practical cases we are dealing with, these fields are too small to produce any significant effects. A virtual gaussmeter able to measure both DC and AC magnetic fields – based on a Honeywell SS495A1 Hall-effect sensor IC in conjunction with properly designed amplification and filtering circuitry – was presented in [14].

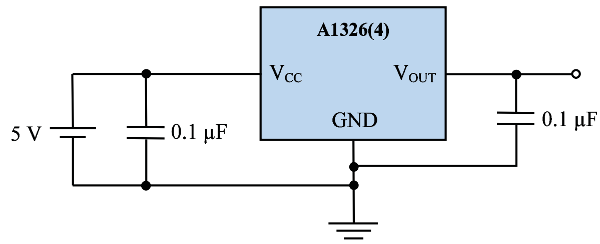

Fig. 3. The electrical scheme of the magnetic field probes.

Fig. 4 shows the transverse magnetic field probe realized with the A1324 sensor IC, which provides a measurement range of approximately ±500 G. The location of the Hall-effect sensor IC is indicated by a square marker, whose role is allowing for correct positioning of the probe in the DC magnetic field to be measured. The second probe – developed with the A1326 sensor IC – features a similar design, while providing a measurement range of approximately ±1000 G. As can be easily observed, the probes connect to the instrument trough a 3.5 mm stereo jack plug.

Fig. 4. Transverse magnetic field probe based on the A1324 sensor IC.

B. *Data acquisition module*

The main board of the gaussmeter is a data acquisition module developed around the PIC18F4550 microcontroller, which is similar to that presented in a previous project [15]. Basically, it implements the block diagram in Fig. 1, providing connectors for the analog input signal (from the magnetic field probe), 5 V supply voltage, ICSP programming interface, LCD module, push buttons and USB communication.

Hardware interfacing for USB communication is very simple, consisting only in a type B connector. However, when using Full Speed operation for USB, the microcontroller must have a 48 MHz clock for the USB module. The first thing you can do is to use a 48 MHz crystal, but there is a very important drawback: such a crystal will generate high noise. PIC18F4550 greatly solves this problem. It includes a PLL frequency multiplier, which allows a wide range of clock speeds, from 4 MHz to 48 MHz. Noise cancelation is handled inside it. So, we are going to use this feature to produce Full Speed operation for USB.

Another very useful feature of PIC18F4550 is represented by the serial ICSP interface, which allows programing the PIC while attached to the application circuit. Hence, the data acquisition module features a 5-pin header to make this connection quick and easy. The PIC programmer – we use PICkit2 from Microchip Technology – plugs directly into this connector, as illustrated in Fig. 5. The ICSP circuitry is designed to isolate the programmer from the rest of the circuit during the programming.

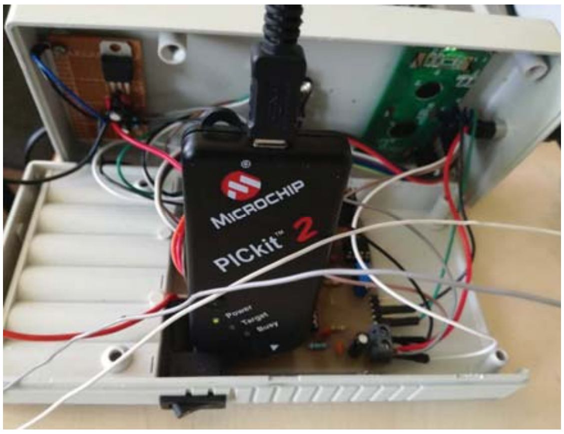

Fig. 5. PICKit2 programmer connected to the data acquisition module during the instrument assembly and testing.

As already mentioned, the firmware loaded in the microcontroller is written in *mikroC for PIC* compiler. It continuously reads the input DC voltage, calculates the magnetic flux density by dividing this voltage by the sensor IC sensitivity, depending on the selected probe, and sends the result to the LCD display. If there is a valid USB request, the data will be transferred to the PC. In order to enable USB communication, the microcontroller was configured as a HID (Human Interface Device), a class of USB devices such as keyboard, mouse and joystick. When connected to the PC, the gaussmeter will be detected without any problem by the operating system.

C. Instrument assembly

After programming the microcontroller, the data acquisition module along with a blue LCD display and a small size 5 V power supply board were incorporated into a Maszczyk ABS-103B enclosure with battery compartment (93 mm x 190 mm x 41 mm), as illustrated in Fig. 6. A 3.5 mm female jack socket is mounted on the top of the enclosure for connecting the probe. Two LEDs (red and blue) are used for indicating the polarity of the measured DC magnetic field if desired. The two push buttons are used for selecting the correct probe when the device is switched on, as well as for changing the measurement unit and activating the polarity detection function during the measurement process. The ON/OFF switch and USB connector are each mounted on one side of the ABS enclosure.

Fig. 6. Instrument prototype in operation.

IV. FUNCTIONALITY

The operation of the instrument is straightforward. When switching on the device, the user is asked to select the desired magnetic field probe by long pressing one of the two white buttons. If no button is pressed, the last probe used will automatically be selected. (Fig 7.*a*). By default, the instrument displays magnetic flux density in units of G, as indicated in Fig 7.*b*. By pressing the UNIT button, the measurement unit will change to mT (1 mT = 10 G), as shown in Fig. 7.*c*. The unit returns to G by pressing this button again. Depending on the selected probe, the instrument provides a measurement resolution of 1 G and 0.5 G, respectively.

a)

b)

c)

Fig. 7. Information displayed during the operation: a) selection of magnetic field probe; b) selection of gauss unit; c) selection of millitelsa unit.

By pressing the POLARITY button, the two field polarity LEDs will be activated: blue – indicates proximity to the South pole; red – indicates proximity to the North pole. By pressing the POLARITY button again, the LEDs will be disabled. Fig. 8 illustrates the indication of the field polarity (in this case, the proximity to the South pole).

Fig. 8. The indication of the proximity to the South pole.

V. Application Software

The LabVIEW application software operates under Windows 7/Vista/XP and extends the basic functionality of the gaussmeter by adding new functions, such as graphical display of the magnetic flux density, determination of the maximum and minimum magnetic flux density values and data recording options. Basically, its graphical user interface (GUI) consists in two windows, *Configuration* and *Live Data & Recording*, as shown in Fig. 9. First window allows selecting the VISA resource name, visualize the transferred USB data, etc. The second window is used for displaying the magnetic field data and configuring the data recording. The current values of magnetic flux density can be recorded at predefined, regular time intervals or at any desired moment. The data are stored in text (LVM) files.

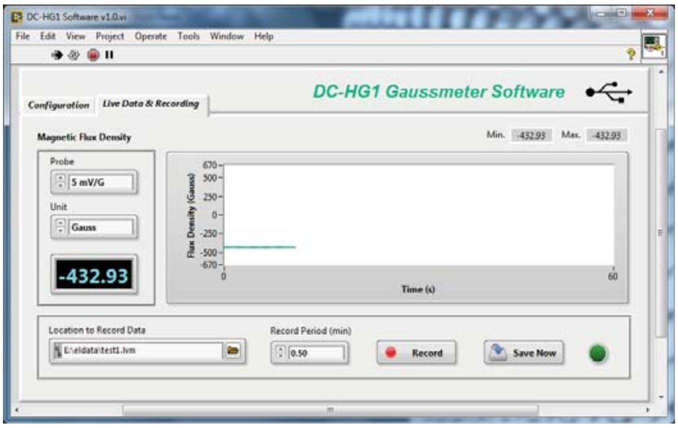

Fig. 9. GUI of the LabVIEW application software.

VI. Conclusions

A low-cost digital gaussmeter for measuring DC magnetic fields up to ±1000 G was developed. The instrument provides ease of use, portability, as well as intuitive LabVIEW application software for remote PC operation via USB. The instrument can be used for magnetic flux density measurements on various magnetic and electromagnetic components, for educational purposes, etc.

Future research will address the enhancement of the measurement resolution, by using an external analog-to-digital converter with I^2C interface, and the extension of the measurement range to ±3000 G (±300 mT), by using new linear Hall-effect sensor ICs. Improvements in firmware and application software are also under consideration.

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