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Magnetic Fields Measurement with AMR Sensors

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Abstract – **In this paper a magnetic field measuring system in a form of a LabVIEW virtual instrument is proposed. The magnetic field is converted into proportional voltage by two orthogonal placed anisotropic magnetoresistive (AMR) sensors. A simplified signal conditioning circuit is designed, developed and presented in the paper. More of manipulations needed to obtain magnitude and direction of magnetic field are planned to be done by portable data acquisition board and developed software. Finally, example for complete system is given and accuracy and application is considered.**

Keywords – **AMR sensors, LabVIEW, Portable DAQ, Virtual instrumentation.**

I. Introduction

Measurement of magnetic field has vastly expanded as industry has adapted a variety of magnetic sensors to detect the presence, strength, and direction of magnetic fields generated from the Earth, permanent magnets, magnetized soft magnets, vehicle disturbances, and fields generated from electric currents. Magnetic sensors can measure these properties without physical contact and have become the main sensing component of many industrial and control systems. The technology for sensing magnetic fields has also evolved driven by the need for improved sensitivity, smaller size, and compatibility with electronic systems.

Measurement of weak magnetic fields which has a typical strength of between approximately 10 – 100μT requires a sensor with very high sensitivity. With their inherent high sensitivity, anisotropic magnetoresistive (AMR) sensors are well suited to sensing relatively small fields. Typically these sensors are by nature bi-stable and conventional techniques used to stabilize such sensors, including the application of a strong field in the *x*-direction from a permanent stabilization magnet, are unsuitable as they reduce the sensor's sensitivity to fields in the measurement, or *y*-direction [4, 5]. To avoid this loss in sensitivity, applying brief, strong non-permanent field pulses of very short duration can instead stabilize AMR sensors. This magnetic field, which can be easily generated by simply winding a coil around the sensor, has the same stabilizing effect as a permanent magnet, but as it is only present for a very short duration, after the pulse there is no loss of sensitivity. Modern AMR sensors, such as KMZ51, specifically designed for weak field applications incorporate this coil on the silicon.

This paper describes how to realize virtual system for magnetic field measurement using the AMR sensors KMZ51 from NXP (Philips Semiconductors). To provide an understanding of the sensor elements, the magnetoresistive effect and the optimization of the sensor characteristic by using barber pole structures are described briefly. In the following, the main building blocks of an virtual system for magnetic field measurement are shown, which consists from two sensor elements for measuring the *x*- and *y*-components of the field in the horizontal plane, a signal conditioning unit, data acquisition board and a portable computer platform.

The signal conditioning unit´s basic function is to amplify the sensor output voltages, in order to provide reasonable input signals for the following DAQ board. Beyond that, offset elimination is an essential task. Practical methods to fulfill all these tasks either in hardware or software are given in presented paper.

II. Benefits of AMR Sensors

Because of their high sensitivity, magnetoresistive sensors can measure very weak magnetic fields and are thus ideal for application in electronic compasses, earth field correction and traffic detection. AMR sensors make use of the magnetoresistive effect, the property of a current carrying magnetic material to change its resistivity in the presence of an external magnetic field. The amount of change depends on the magnetization magnitude and the direction in which the current used to measure resistivity is flowing [2, 4, 5].

If the AMR sensors are to be used to maximum advantage, however, it is important to have a clear understanding of their operating principles and characteristics, and how their behavior may be affected by external influences and by their magnetic history. An AMR is constructed using long thin film segments of deposited permalloy [4, 5]. Figure 1 shows a strip of ferromagnetic material, like permalloy. During deposition of the permalloy strip, a strong external magnetic field is applied parallel to the strip axis. By doing this, a preferred magnetization direction is defined within the strip.

$$R = R_0 + \Delta R \cos^2 \alpha$$

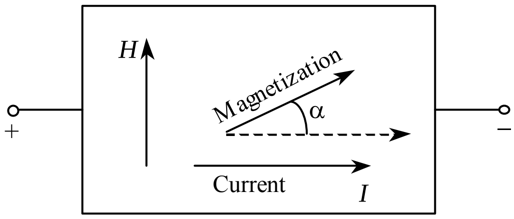

Fig.1. The magnetoresistive effect in permalloy.

In absence of any external magnetic field, the magnetization always points into this direction. In Figure 1, this is assumed to be the *x*-direction, which is also the direction of current flow. An AMR sensor now relies on two basic effects:

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- The strip resistance R depends on the angle a between the direction of the current and the direction of the magnetization;
- The direction of magnetization and therefore α can be influenced by an external magnetic field H_y, where H_y is parallel to the strip plane and perpendicular to the preferred direction.

When no external magnetic field is present, the permalloy has an internal magnetization vector parallel to the preferred direction and $\alpha = 0$. In this case, the strip resistance R has its maximum value R_{max}. If an external field H_y is applied, the internal magnetization vector of the permalloy will rotate around an angle α. At high field strengths, the magnetization tends to align itself parallel to H_y and the rotation angle α approaches 90°. In this case, the resistance reaches its minimum value R_{min}. The equation in the Fig. 1 gives the functional dependence between R and α, where $R_0 = R_{min}$ and $\Delta R = (R_{max} - R_{min})$. Finally, the function of R versus H_y is as follows [2]:

$$R = R_0 + \Delta R\left(1 - \left(\frac{H_y}{H_0}\right)^2\right). \quad (1)$$

H_0 is a parameter, which depends on material and geometry of the strip. Equation (1) is defined for field strength magnitudes of $H_y \leq H_0$. R_0 and ΔR are also material parameters. For permalloy, ΔR is in the range of 2 to 3% of R_0.

It is obvious from this quadratic equation that the characteristic is non-linear and each value of R is not associated with a unique value of H. Furthermore, this characteristic does not allow to detect, whether H_y is positive or negative. The magnetoresistive effect can be linearized by depositing aluminium stripes (called Barber poles), on top of the permalloy strip at an angle of 45° to the strip axis – see fig. 2. As aluminium has a much higher conductivity than permalloy, the effect of the Barber pole is to rotate the current direction by 45°, effectively changing the angle between the magnetisation and the electrical current from α to (α – 45°).

In a typical configuration, four of these sensing elements are connected in a Wheatstone bridge to permit measurement of both field magnitude and direction along a single axis. In one pair of diagonally opposed elements, the Barber poles are at +45° to the strip axis, while in another pair they are at –45°. A resistance increase in one pair of elements due to an external magnetic field is thus matched by a decrease in resistance of equal magnitude in the other pair. The resulting bridge imbalance is then a linear function of the amplitude of the external magnetic field in the plane of the permalloy strips, normal to the strip axis.

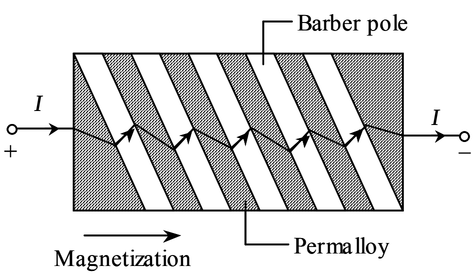

Fig. 2. Linearization of the magnetoresistive effect.

The best results are obtained from a Wheatstone bridge configuration when a current source rather than a voltage source drives the bridge. This arrangement helps to:

- ✓ reduce the temperature drift of the sensor;
- ✓ improve the bridge linearity;
- ✓ increase the sensitivity of the sensor.

AMR sensors can be bulk manufactured on silicon wafers and mounted in commercial packages, permitting automated assembly with other circuit and systems components. They also offer high sensitivity, small size, and noise immunity. Based on the described principles, there are various AMR sensors. The main characteristics of the more popular and accessible of them are given in [3].

III. Virtual System for Magnetic Field Measurement

A. Hardware design of the system

The block diagram of designed system for magnetic field measurement is shown in fig. 3. The system consists of magnetic field sensors, signal conditioning block, portable USB data acquisition board (DAQ) and portable computer.

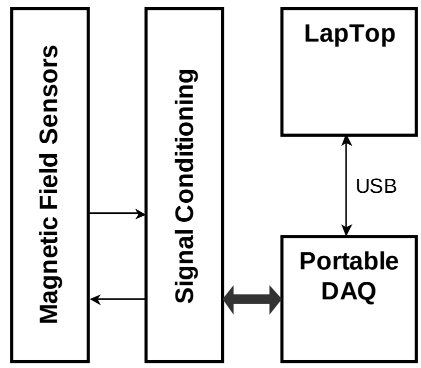

Fig. 3. Block diagram of measurement system for magnetic field.

Magnetic field sensors. In present development the strengths of two horizontal magnetic field components have to be measured. The first one is in heading direction (H_x) and the other – sideward (H_y). This requires two magnetic field sensors both aligned parallel to the earth´s surface, but rotated by ninety degrees with respect to each other. For measuring low magnetic fields two low cost AMR sensors KMZ 51 are selected [5]. Each of selected sensors comprises a set/reset coil needed for offset elimination and a coil for the compensation of sensitivity and temperature drift.

Signal conditioning. The purpose of this block is to transfer output voltages proportional to the field strengths H_x and H_y respectively. Therefore, the signals delivered by the magnetic field sensors have to be amplified and offsets have to be eliminated. The schematic of signal conditioning circuit is shown in fig. 4. Two precision instrumentation amplifiers INA122, each per sensor, achieve the amplification of the signals. Connecting a single external resistor, R_G, as shown on the fig. 4, sets gain of the INA122. Thereby the gain G is calculated by equation [8]:

$$G = 5 + \frac{200\ \text{k}\Omega}{R_G}. \quad (2)$$

Gain of 650 is selected in order to measure magnetic field up to ± 60 μT without saturation.

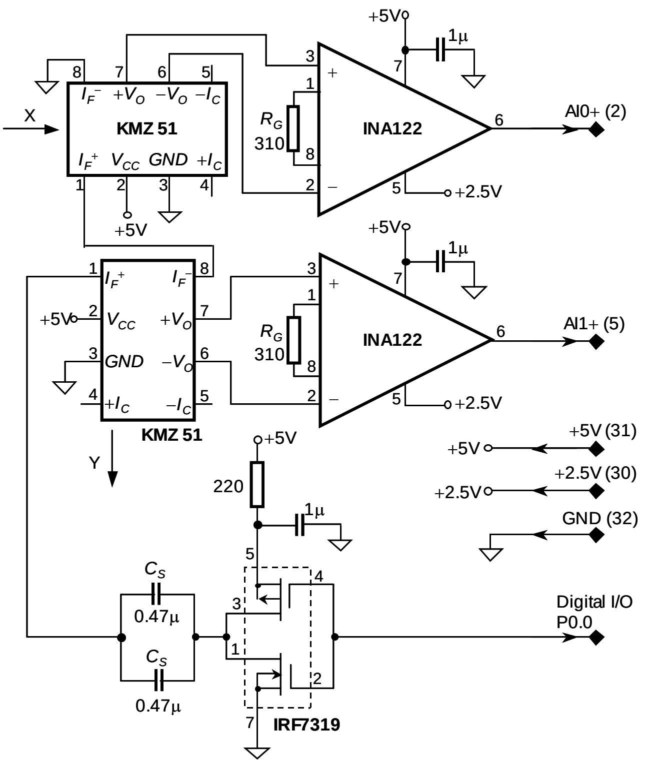

Fig. 4. The circuit for signal conditioning.

In order to calculate and subtract sensor's offset a technique called "flipping" can be used, which is similar to the "chopping" technique used for the amplification of small electrical signals [5]. When the bi-stable sensor is subjected to a reversible magnetic field in its flipping direction, its internal magnetization and its characteristic V_{out} vs. H_y is reversed or "flipped". If the flipping is done repetitively, the desired output voltage will change polarity, but the offset voltage does not. This allows calculating the sensor´s offset by equation:

$$V_O = \frac{V_P - V_N}{2}, \quad (3)$$

where V_O is calculated offset voltage, V_P and V_N are measured voltage for positive flipping current and for negative one respectively.

Flipping generator generates the current pulses at a repetition frequency, determined by software because the frequency is not critical, considering the flipping function itself [5]. The choice of frequency is a trade-off between average current consumption on the one hand and response time and output ripple on the other hand.

As the digital I/O of DAQ (P0.0) passes from high to low, that switches P-channel MOSFET of the IRF7319 power driver on. This charges C_S capacitors and a short positive pulse is passed to the flipping coil of KMZ51. For a low-to-high transition at the output of digital I/O, forces N-channel MOSFET to conduct, discharging C_S and providing a negative current pulse through the coil. KMZ51 require flip current pulses of typically ±1 A for duration of up to 3 ms.

On the right site of the fig. 4 are shown connections corresponding to inputs and outputs of selected data acquisition board.

Low-cost portable DAQ board. As can be seen from the fig. 4 a selected data acquisition board must ensure at least two analog inputs, one digital output and two voltage references. It is desirable also that the power supply of the DAQ to be internal for the system i.e. via computer interface. There are many DAQ boards that fulfill these tasks. For present development a low cost DAQ board NI USB 6008 is selected.

B. Software design

As base software for presented virtual system for magnetic field measurement the graphical programming environment LabVIEW is selected. One of the more power features of LabVIEW is the build in connection with DAQmx data acquisition device drivers. DAQmx is a new type of drivers that saves development time and improves the performance of data acquisition applications [6].

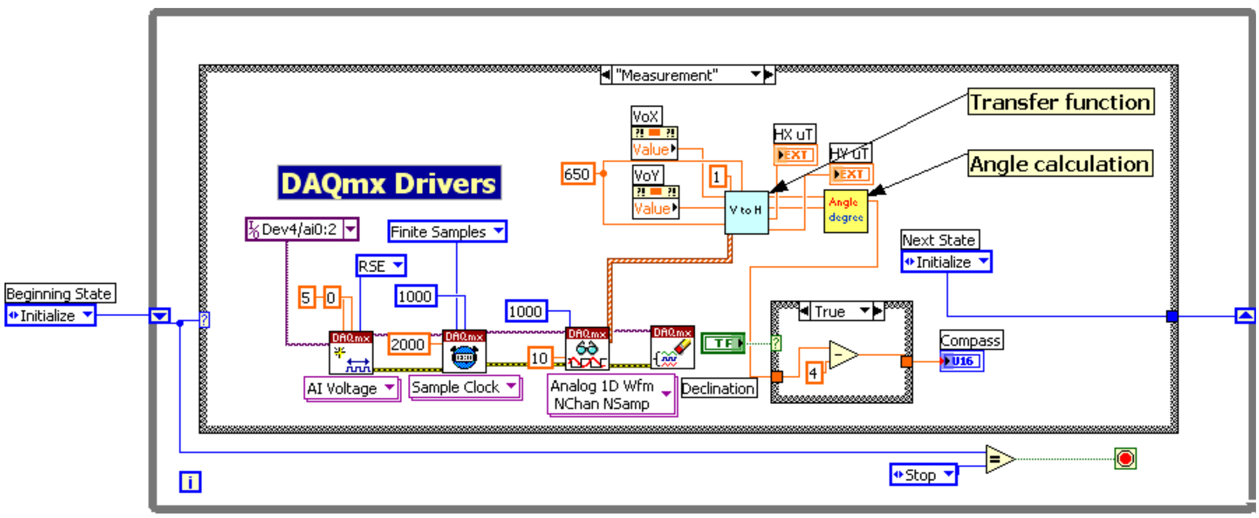

Fig. 5. The software code of virtual system for magnetic field measurement.

In LabVIEW is possible all of the functionality of a multifunction device to be programmed with the same set of functions, because polymorphic software component accepts multiple data types for one or more input and output terminals. Another significant feature of the DAQmx architecture is measurement multithreading which means that multiple data acquisition operations can occur simultaneously.

The developed software that controls presented virtual system for magnetic field measurement is shown in fig. 5. This figure represent a template for so called *Classic State Machine* design pattern.

State Machines provide enormous flexibility and expandability. This design pattern allows the code to jump from any state to any state and each state can determine the run condition, allowing it to stop after any state.

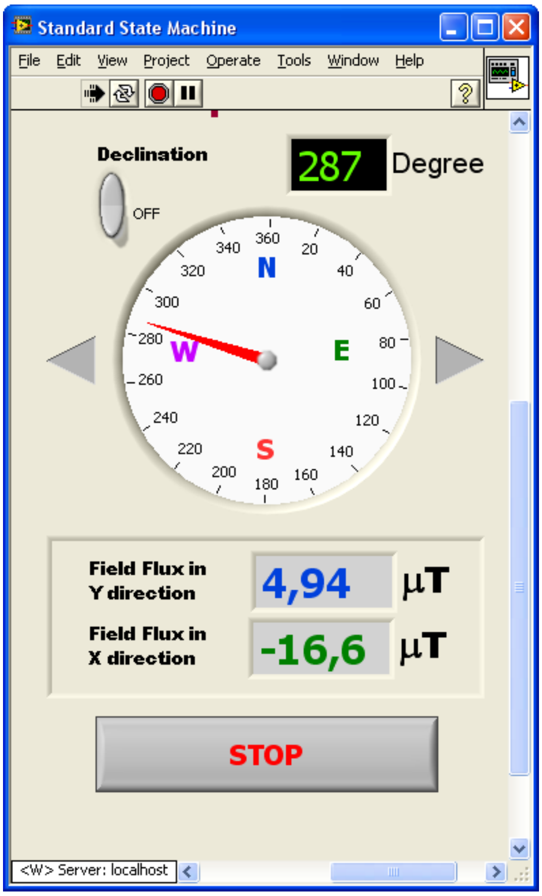

Fig. 6. The front panel of the virtual system for magnetic field measurement.

To use a *State Machine*, the application must be divided into a series of states. This can be done during the planning phase using a properly delineated requirements specification or design document, or during the implementation phase using experience and intuition. The *State Machine Diagram* is a fundamental component of unified modeling language and an ideal method for defining the primary states of an application. In presented development six states of application are planned. These states are executed consecutively. The first one is *Initialize*. Follows: *Measurement of* V_P, *Measurement of* V_N, *Offset calculation*, *Measurement of magnetic field*, *Check up for Stop* and again *Initiate*. The programming code is executed in *While* loop as long as *Stop* event occurred.

C. Experimental Results and Applications

The front panel of developed system for magnetic field measurement is shown in fig. 6. Angle indicator for an azimuth reading covers the central part of the figure. The azimuth that is measured with the system indicates the heading direction relative to magnetic north. The heading direction relative to geographic north is achieved by mathematical correction of declination. Indicators for values of magnetic flux in *Y* and *X* directions are placed under angle indicator.

A number of experiments were done with presented simplified virtual system in various places and different conditions. If applications require an azimuth direction indication only, then used circuitry is sufficient. Achieved results show that direction of magnetic field can be obtained with relatively good accuracy (±5 degrees). However if the exact magnitude value of the weak magnetic field have to be measured, the presented development is not appropriate. For such applications more complicated circuits (closed-loop and temperature compensated [4, 5]) should be used.

IV. Conclusion

Design, development and implementation of virtual system for magnetic field measurement based on AMR sensors, DAQ board and graphical programming environment is presented in this paper. As signal conditioning unit a simplified schematic is designed and suggested. The measuring accuracy can be improved by additional more complicated circuitry.

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