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Multilayer Based Technology to Build RTD Fluxgate Magnetometer

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Abstract

In this paper we discuss the main features of the Residence Times Difference Fluxgate Magnetometer. A low-cost technology, negligible onboard power requirements and the intrinsic digital form of the readout signal are the main advantages of the proposed strategy. Results obtained show the possibility to realise low-cost devices exploiting Printed Circuit Board (PCB) technology for applications requiring resolution in the nanotesla range as the ferrous object (or particles) detection, being the performance obtained suitable to detect the presence or the transit of ferrous materials via their interaction with the geomagnetic field.

Keywords: magnetic sensor, fluxgate, PCB technology sensor

1. Introduction

Fluxgate magnetometers have always been of interest to the technical and scientific communities as practical and convenient sensors for vector magnetic field measurements in the range of microtesla requiring a resolution of hundreds of picotesla at room temperature, and they find applicability in fields such as space, geophysical exploration and mapping, non destructive testing, as well as assorted military applications; very good example of past and emerging applications of Fluxgate magnetometers can be found in [1]. The mostly frequently used principle of Fluxgate magnetometers is the second harmonic detection of the output voltage [2]. This readout scheme covers most of the Fluxgate literature and it is commonly implemented by measuring the amplitude of the second-harmonic content of the output signal.

Recently, the possibilities offered by new technologies and materials in realizing miniaturized devices with improved performance, have lead to a renewed interest in seeking solutions for how to reduce cost and size of Fluxgate sensors. Miniaturization of the sensors itself is complicated by the rapid increasing of the magnetic noise (leading to lower resolution) with device dimensions, and general practical rules for achieving high sensitivity (high number of turn, high cross-sectional sensor area, high driving current) are in contrast with scaling or power consumption [2].

This consideration has driven the idea to realise Fluxgate sensors in Printed Circuit Board (PCB) technology, which represents a good compromise between the costs and device dimension [3, 4].

Among Fluxgate working principles available in the literature, the PCB based Residence Times Difference (RTD) Fluxgate magnetometer [5, 6], subject of this paper, presents some advantages. Its working principle is based on a time domain readout, i.e. the target magnetic field information is carried out on the position in time of the spikes whose the output waveform is constituted. This way to operate a Fluxgate magnetometer presents interesting features especially in view of reduced cost, power consumption and nevertheless dimension scaling.

2. RTD Fluxgate Working Principle

An RTD Fluxgate is based on a two-coils structure (a primary coil and a secondary coil) wound around a suitable ferromagnetic core having a hysteretic input-output characteristic (see Fig. 1). A periodic driving current, I_e, is forced in the primary coil and generates a periodic magnetic field, H_e parallel to the geometry of the core. This geometry is adopted to guarantee uniformity of magnetic field along the ferromagnetic core. A target field H_x is applied in the same direction of H_e; the secondary coil is used as pick-up coil and the output voltage V_{out} carries information on the target magnetic field.

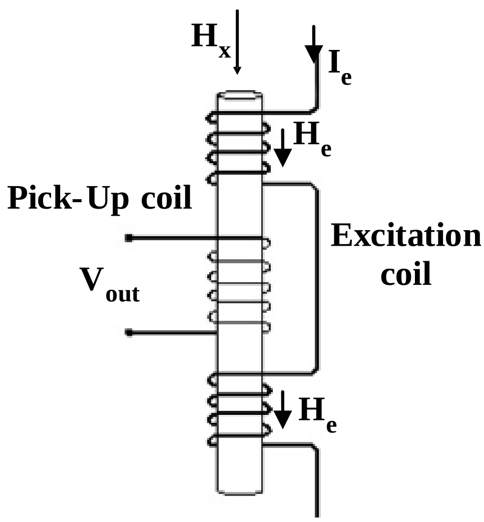

Fig. 1. RTD Fluxgate sensor structure.

The basic idea is that the magnetic core has two commutation thresholds and a two state output, whose behaviour can be described via bistable dynamics governing a double-well potential energy function. The magnetization m of the magnetic core is governed by the excitation field, H_e, produced in the primary coil, and the bistable potential energy function, which underpins the crossing mechanism between the two steady magnetization states of the magnetic core [5]. In order to reverse the core magnetization (from one steady state to the other one), the driving field (H_e) must cross the switching thresholds of the magnetic core. In the case of a time-periodic excitation having amplitude large enough to cause switching between the steady states and in the absence of any target field, the hysteresis loop (or the underlying potential energy function) is symmetric and two identical Residence Times (time intervals spent by the magnetization in the two steady states) are obtained. The presence of a target dc signal (H_x) leads to a skewing of the hysteretic loop with a direct effect on the Residence Times, which are no longer the same. Finally, we assume a sharp hysteretic characteristic for the magnetic core allowing to infer that switching between the two stable states of the magnetization occurs instantaneously when the applied magnetic field exceeds the coercive field level H_c.

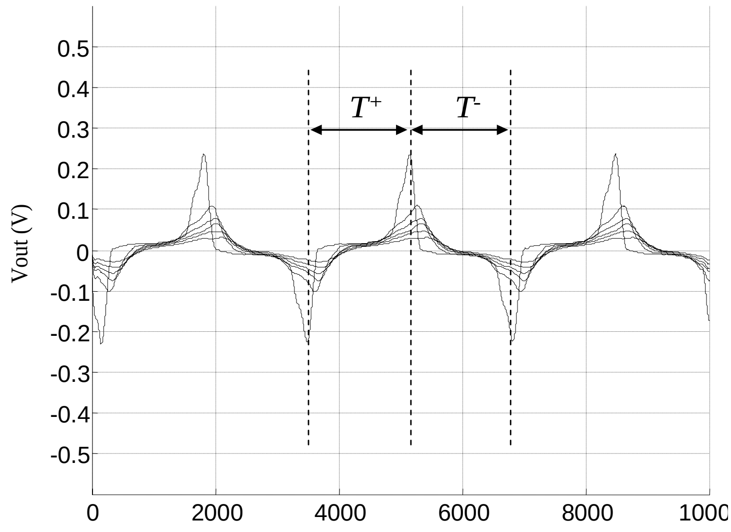

Fig.2. Typical pick-up coil output voltage.

Under these conditions, the device operates almost like a static hysteretic nonlinearity, e.g. a Schmitt Trigger and the Residence Times Difference can be computed from the pickup coil output voltage (V_{out}), whose spikes represent the state transitions; an example of experimental signals is shown in Fig. 2 along with the Residence Times.

Models and design rules of this read-out strategy are elucidated in [5, 6].

3. Multilayer Based Technology for Sensor Construction

The technological approach we present pursues the possibility to conceive a small volume production technique to realize multilayer PCB based sensor, where the ferromagnetic material is one of this layers.

An Amorphous Metal (also known as metallic glass alloys) has been chosen for the magnetic core layer due to its suitable hysteretic characteristic, which encourages the use of a readout strategy based on the estimation of the RTD. In particular, the Magnetic Alloy 2714 As Cast (Cobalt-based), by Metglas® has been adopted for its very sharp characteristic [7].

In this process, a patterned Metglas foil (wet etching is adopted for Metglas patterning; the patterning lets to realize optimized Metglas shapes) is embedded between two FR4 PCB layers.
A simplified process description can be summarized by the following steps:

- the patterned Metglas is aligned respect the two RF4 layers;
- the patterned metal layers are aligned to the sensor structure according to layout design;
- the whole layers are pressed, while heating the whole system up to 200 °C.

Finally, the vias formation between the lower and upper layer let to complete the windings for the coils; typical geometric characteristics are reported in Table 1.

Table 1. Technology layers and their thickness.

Minimum metal width	200µm
Minimum Interspaces between metal lines	200µm
Metglas Etching mask resolution	100µm

Set the Technology, further step consisted of the sensors layout conception; different Metglas shapes and sensor geometry were included in the layout in order to realize a set of 50 testing devices in a single run; a set of prototypes realized with this approach are showed in Fig.3; in Fig. 4 a backlight view of the PCB sensor showing the shape of the embedded Metglas is presented.

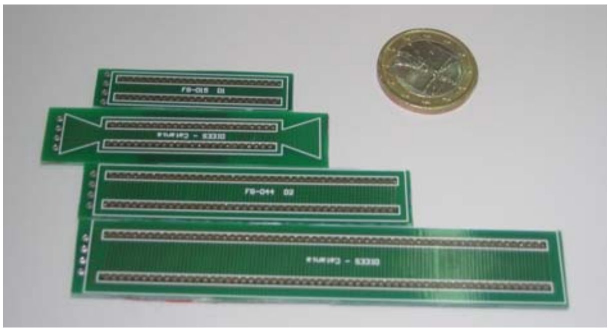

Fig.3. Image of a set of PCB integrated Fluxgate sensors.

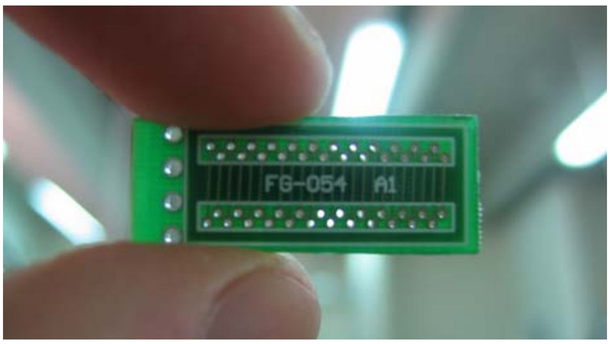

Fig. 4. Backlight view of the PCB sensor showing the shape of the embedded Metglas.

4. Test Results

There are two methods for the sensor calibration. The first one uses the Earth's field, the second needs calibration coil. Practical reasons exclude the use of the earth's field, which requires precise globe positioning of the sensor under test.

For the measurement of sensor noise, environment with very low magnetic field is required. Shielding of the ambient field is usually performed by ferromagnetic shielding made in the form of a multilayer cylinder from Permalloy or amorphous materials.

The calibration instrument adopted here consists of a cylindrical solenoid and a three layers Metglas magnetic shield.

The RTD is estimated from the output signals of Fig. 2; the output is converted into a dichotomous signals by a trigger (see Fig. 5), passed to a 20 MHz acquisition board and elaborated with a LabVIEW® routine.

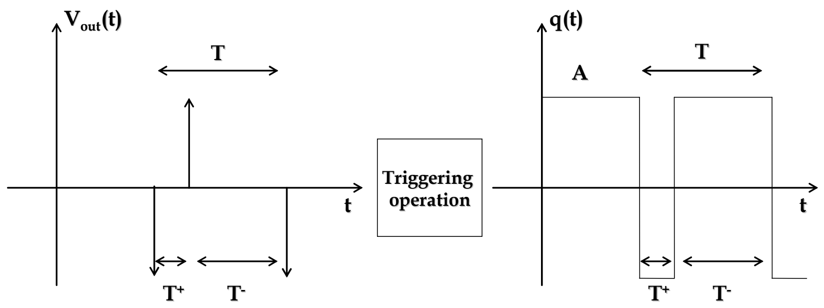

Fig.5. Triggered output waveform retaining the RTD information.

The change of the RTD versus the magnetic field generated by the calibration coils let us to estimate the sensor sensitivity. Fluctuation of the RTD in zero-field condition let a characterization in terms of noise; Table 2 summarizes typical figure of merit of the RTD-Fluxgate prototypes under test.

Table 2. Main figure of merit of RTD-Fluxgate.

Sensitivity	0.2 (μs/nT)
Noise level peak-peak	10 (nTpp)
Power Consumption (Absorbed current peak-peak)	40 (mApp)

5. Conclusions

A non-conventional read out strategy for highly sensitive Fluxgate magnetic sensors has been presented in this work.

Instead of working, as in the traditional approach, with the output voltage amplitude, we exploited here the hysteretic magnetic core to estimate the differences in the Residence Times in the two stable states of the potential energy function.

The proposed approach is significantly efficient from several points of view: it requires simpler sensor architecture; the bias signal requires lower amplitude than in conventional readout schemes, thus reducing power consumption and thereby broadening the set of possible fields of applications; the sensor output has an intrinsic digital form; the devices show high sensitivity and a suitable resolution.

Experiments performed on a PCB technology Fluxgate has shown the feasibility of using the RTD-Fluxgate in many industrial and security applications requiring small dimensions and low-cost device, reduced power consumption and a resolution in the nanotesla range.

Acknowledgements

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