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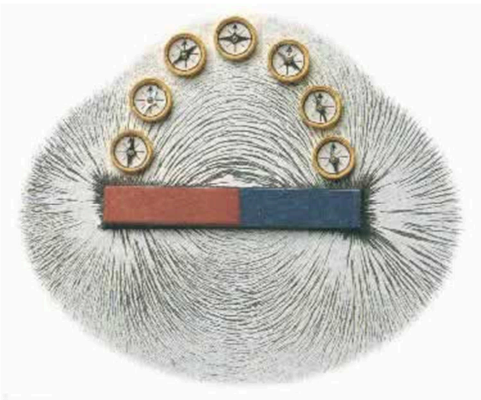
RTD FLUXGATE MAGNETOMETERS



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Preface

Fluxgate magnetometers since long time represent a major subject of investigation thanks to their capability of detecting weak magnetic fields at room temperature. However, apart of the significance as highly performing sensors, fluxgates are very interesting hysteretic systems that can also provide very rich nonlinear dynamics when suitably connected to realize nonlinear ring oscillators. This mixture of subjects into a single device such as exploitation of material properties, nonlinear dynamic behaviors, mathematical modeling, measurement methodologies, readout electronics make the investigation on fluxgate magnetometers a very challenging activity on which many highly skilled researchers confront themselves throughout the international scientific community.

This PhD Thesis is full of mathematical efforts for accurate device modeling and for a rigorous definition of the measurement methodology but also it carries a bright engineering view of the subject whenever clever intuitions and novel ideas have been converted into reality and in working devices.

However this thesis cannot tell all that Salvo La Malfa has done during his years spent as PhD student; in particular it cannot be written "how well", "how autonomously", "how seriously and rigorously" and "how enthusiastically and constructively" he has worked.

Nevertheless this work represent a cornerstone on the subject of fluxgate magnetometers when Residence Times Difference is used as readout methodology; the various chapters report very basic information on the device model and properties, but also describe the measurement methodologies and the device calibration procedures, last but not least several new ideas are discussed and their conversion to reality is presented.

It is much more than a Thesis and it will represent a textbook for those that are approaching the subject and that are aiming to continue on this research activity.

It has been therefore a great pleasure for me being invited to write few words of presentation for this PhD Thesis; I have witnessed Salvo La Malfa working during these years in our lab and I have appreciated his scientific and technical qualities, it has been a sincere pleasure for me to see him growing toward his full maturity and I have enjoyed working together with him. I sincerely feel as owing many thanks to Dr Salvo La Malfa for his time shared with me and I fell lucky to have had the opportunity of interacting with him in a short part of what I'm it will be his bright career.

Catania, December 2011
Salvo Baglio

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.

The mostly frequently used principle of Fluxgate magnetometers is the second-harmonic detection of the output voltage. 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 Fluxgate output voltage; the output is demodulated by a phase sensitive detector back to dc frequency. The analog readout circuit, normally operated in feedback configuration to increase the operating range, works at frequency between 500 Hz and 100 kHz.

Recently, the possibilities offered by new technologies and materials in realizing miniaturized devices with improved performance, have led to a renewed interest in seeking solutions to optimize Fluxgate sensors, reduce cost and size. Miniaturization of the Fluxgate 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 budget. Many examples of Fluxgate in PCB and CMOS technology, may be founded in the scientific literature. On the other end, the Residence Times Difference (RTD) Fluxgate magnetometer introduced in this Thesis represents an example on how to reconsider an old idea and show that, with the technologies currently available (new materials and electronics), now it works well; a very simple sensor structure, negligible onboard power requirements and the intrinsic digital form of the readout signal are the main advantages of the proposed strategy, over the conventional Fluxgate which require large excitations to improve the quality of the output signals.

The working principle is in fact based on a time domain readout, i.e. the magnetic field information is carried out on the time position of spikes in waveform. This way to operate a Fluxgate magnetometer presents interesting features especially in the prospective of the dimensions scaling; the model of the sensor reveals that the sensitivity of the device is slightly related to its dimensions and that the regime of highest sensitivity matches that for less on board power consumption; moreover the readout strategy based on time reading can be naturally implemented exploiting the features of digital circuits. In this Thesis the research work on RTD Fluxgate is presented along with the development of models, prototypes and their characterization. Classical but also new technological approaches to realize low-cost Fluxgate magnetometers are proposed.

In chapter 1 an overview of RTD Fluxgate magnetometer is presented, together with mathematical and physical models that underpin the device operation.

The second chapter is mainly about the metrological characterization of the device. In this section, details regarding the actual prototypes and the measurement setup are discussed, together with some interesting experimental results.

A novel behavioral model for magnetic hysteresis is presented in chapter 3. This work has been motivated by the need to overcome the limitations of traditional approaches when dealing with the SPICE simulation of soft ferromagnetic materials. The model is discussed in details and simulation results are also presented.

In the fourth chapter two applications, which have important implications from the practical perspective, are discussed, highlighting the advantages of the RTD Fluxgate magnetometers over the traditional approaches.