Preface

Nowadays sensors are part of everyday life in a wide variety of fields: scientific applications, medical instrumentation, industrial field, ... and, last but not least, popular mass production and low-cost goods, like smartphones and other mobile devices. Markets and business behind the field of sensors are quite impressive. A common trend for consumer applications is miniaturization which requires, on one side, a lot of research, development efforts, and resources but, on the other hand, allows costs and final application size reduction. In this scenario scientific community and industries are very active to drive innovation.

I started my research activity in 2009 in the field of imaging sensors and microelectromechanical sensors. During this period I had several opportunities to write technical papers and articles, to participate in conferences, to exchange knowledge with technical experts, to advise students, and to give some lectures at the university. The fact that I particularly enjoyed sharing my knowledge made me think of writing a book one day in my life.

This book deals with compasses for consumer applications realized in micro-technologies, describing a full path from specifications to prototype and preparing the way to industrialization and commercialization. This book does not pretend to be fully comprehensive in each single step of the development phase, rather it is meant to show the overall process, all the way from some specifications (not much more than a few numbers) to a concrete working sensing system. The book is intended for a wide audience, especially for researchers who want to develop their prototypes and people who want to go beyond academic research toward industrialization. The book also includes some introductory concepts about microelectromechanical systems and therefore can be considered for undergraduate and graduate courses too. The author wishes that this manuscript fulfills his target. Even though some sections deal with theoretical aspects, the book wants to be primarily a "guide" (independent from the topic itself of magnetic field sensors) conveying a practical approach, with pragmatic guidelines and design choices, and keeping an eye on the final target, industrialization and mass production. This book cannot describe every single detail (this process involves a lot of people with different skills and expertise according to the development phase) but it is intended to mention all the major

steps of this research and development process, highlighting where possible critical aspects or weak points can arise and how to forecast and handle them. I would like to go through this, taking advantage of my years spent in the scientific world as a researcher but also targeting a development for mass production products. These two worlds are at the same time complementary and in contrast. This book deals with Lorentz force sensors implemented in MEMS technology but general guidelines, methodology, and development flow are applicable to any other development project related to microsensors.

This book is organized into eleven chapters.

Chapter 1 introduces the topic of the book, highlighting motivations and objectives.

Chapter 2 shows a methodology from specifications to the definition of a concept. Main requirements for consumer market products and specifications are analyzed in detail, followed by the choice of transduction principle. Finally, a brief overview of the state of the art is proposed, to review some scientific works published in the literature. Main features of each work are summarized in a table and compared to given specifications for the development of the prototype proposed in this book.

Chapter 3 deals with Lorentz force magnetometers and their working principle. After an introduction about the dynamic of MEMS and capacitive readout principle, basic properties of Lorentz force transduction principle are presented, applied to a micromachined suspended structure. A new design approach of mechanical sensors at a fixed resonance frequency is shown, supported by the study and development of a theory about sensitivity in the free molecular flow regime, which applies for the pressure range of typical industrial packages. Finally, a brief introduction to thermomechanical noise is provided in order to discuss intrinsic resolution of devices.

In Chap. 4 a behavioral model at system level is illustrated, which is developed to analyze magnetometers dynamics and to set specifications for major system subblocks. Then noise budget partitioning and power budget partitioning are discussed.

Chapter 5 is about mechanical devices design, based on specifications derived at system level and supported by finite element simulations. After an introduction to a micromachining fabrication process, devices layouts and photographs are described.

Chapter 6 deals with the design of an instrument for electromechanical characterization. A detailed description of this measurement platform is provided together with its specifications, design, and performance.

In Chap. 7 electromechanical measures—both static and dynamic—are reported in order to validate the proposed theory about sensitivity and to characterize mechanical properties of devices.

Chapter 8 deals with the development of a setup for magnetic field measurements using implemented devices. After identifying main specifications for driving sensors in order to avoid unwanted additional electrostatic forces, the first part of this chapter shows the design of a bipolar differential current generator. The following sections focus on the readout of the capacitance variation analyzing different solutions in terms of complexity of the architecture and noise and taking into account the

overall assembling of mechanical part, driving and readout electronics. Finally experimental measures are reported.

Chapter 9 reports about ASIC architectures and design. A Verilog-A model is also shown to support electromechanical coupled simulation in Cadence environment. Experimental measurements with a multi-chip (MEMS + ASIC) prototype are reported.

Chapter 10 gives an overview of main steps toward industrialization of the presented prototype.

Finally conclusions are reported in Chap. 11.

The work presented in this book is the result of scientific research during years 2010–2012 when the author was a Ph.D. student at Politecnico di Milano in Italy, in cooperation with STMicroelectronics and visiting researcher at Berkeley Sensor & Actuator Center (BSAC), University of California, Davis, CA.

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