SOMMARIO

Grazie ai recenti sviluppi nel campo delle tecnologie d’integrazione la complessità dei System on a Chip (SoC) è andata via via aumentando. Allo stesso tempo i requisiti in termini di time-to-market ed affidabilità dei prodotti si sono fatti via via più stringenti. Inoltre negli ultimi anni si sono diffuse tutta una serie di nuove applicazioni basate su sensori MEMS e MOEMS in svariati campi di applicazione. L’interesse per questi dispositivi si è via via ampliato grazie al fatto che offrono notevoli vantaggi in termini di consumo di potenza, di bassi costi di produzione (per la fabbricazione è possibile sfruttare le infrastrutture già predisposte per la realizzazione dei circuiti integrati e la produzione in serie) e di ridotte dimensioni, aspetto che ne permette l’integrazione sul medesimo chip dove viene integrata l’elettronica d’interfacciamento. Il principale svantaggio è la necessità d’interfacce più complesse rispetto ad altre tipologie di sensori.

Per far fronte a tutti questi requisiti e sfide, le compagnie hanno rivisto nel corso degli anni i tipici flussi di design, e ne hanno sviluppato di nuovi come l’approccio basato sulla Universal Sensor Interface e l’approccio Platform Based. Questi due flussi di design hanno però alcuni svantaggi. Il primo paga l’alta versatilità in termini di basse prestazioni, il secondo al costo di una lunga fase per l’esplorazione dello spazio architetturale. In questa tesi viene presentato un nuovo approccio, basato sulla piattaforma ISIF sviluppata in collaborazione con SensorDynamics AG, che verte al superamento degli svantaggi del tradizionale flusso Platform Based.

A sostegno dell’efficacia dell’approccio proposto, sono presentati due casi di studio: lo sviluppo di un sistema di misura di portata di acqua basato su un anemometro a filo caldo in tecnologia MEMS con particolare enfasi sulla progettazione del driver ad alta tensione sviluppato per permettere l’interfacciamento della piattaforma ISIF con il sensore di flusso, e lo sviluppo di una nuova piattaforma, l’SD4K, per l’interfacciamento delle più recenti generazioni di sensori MEMS e MOEMS. La piattaforma SD4K è principalmente orientata alla realizzazione di un sistema di proiezione basato su un microspecchio a scansione e su sorgenti di tipo laser. Questa attività di ricerca ha richiesto lo sviluppo di un modello elettrico equivalente del microspecchio, grazie al quale è possibile eseguire simulazioni ad alto e basso livello tenendo in considerazione le principali non linearità del microspecchio (come la non linearità della risposta in frequenza). Il principale vantaggio è una progettazione più accurata dell’elettronica di lettura, di pilotaggio e degli algoritmi software implementati per compensare queste non linearità. Infine viene descritto il progetto del driver ad alta tensione utilizzato per l’attuazione del microspecchio a scansione scelto per la realizzazione del sistema di proiezione.
ABSTRACT

Thanks to advances in integrated technology complexity of System on a Chip has increased very rapidly in recent years while requirements of short time-to-market, high performances and reliability have been increasing. Moreover new applications based on MEMS and MOEMS devices, are currently spreading in a great variety of applications from automotive to optical fields. The interest in these devices is due to low power consumption, low manufacturing cost (that stems directly from batch fabrication and the possibility to exploit the infrastructures already developed for integrated circuit fabrication) and small dimensions, which allow their integration with read out electronics on the same chip or die. However MEMS and MOEMS devices require more complex read out interfaces.

In order to face all these requirements and challenges, companies have reviewed typical design flows, developing new different approaches such as the Universal Sensor Interface and the Platform Based Design. However these two approaches suffer from some drawbacks. The former approach offers high flexibility at the expense of overall performances, the latter requires time-consuming architectural space exploration. In this dissertation the ISIF platform, developed by the University of Pisa in collaboration with SensorDynamics AG, is presented as an effective solution to the traditional Platform Based Design drawbacks.

Two case studies are presented to show the effectiveness of the proposed design flow: the development of a water flow monitoring system with a focus on the design of the high-voltage driver that has enabled the ISIF platform to actuate the MEMS hot-wire anemometer, and the design of a new platform, named SD4K, able to interface the latest generation of MEMS and MOEMS devices. The SD4K is targeted to the development of a projection system based on a scanning micromirror and a laser source system. This research activity has required developing a high level model of the micromirror for the proper design of the read out electronics. Once the model is realized, it is possible to perform high-level system simulations that take into account the effect of micromirror non-linearities (such as the non-linear frequency response) and thus perform a more accurate and careful design of the sensing and driving stages and of the compensation algorithms implemented by software routines. Finally the dissertation presents the design of the high-voltage driver for the actuation of the scanning micromirror chosen for the laser-based projection display application.
Introduction

Complexity of System on a Chip (SoC) design, especially in sensor interfacing and conditioning applications, has been dramatically increasing in recent years thanks to advances in integrated technology while time-to-market requirements have been decreasing. Cost reduction and performance enhancement of sensors are pushing towards the introduction of new electronic applications in an increasing variety of application fields. The designer of electronic devices for sensing applications has to provide complex and effective sensor interfaces in a continuously evolving and competitive market. The critical aspects that have to be overcome to achieve final success reside in facing the latest technology facilities, exploiting recent advances for designing high performance products, which combine optimal features with high reliability, and meeting the market demand for short time to market. The design effort for achieving an optimized sensor interface (with regard to area, performances, low power) on one side and the aggressive market demand for low cost, short development time and high level of final product quality on the other side, have led companies to review typical design flows developing new different approaches such as the Platform Based Design and the Universal Sensor Interface approaches.

This dissertation deals with the development of mixed-signal platforms for sensor conditioning mainly targeting the new generation of MEMS and MOEMS devices for automotive and consumer applications and more in detail on the design of the analog IPs inside these platforms. MEMS and MOEMS devices represent the outstanding state of art for many applications such as communication, commercial, optical and automotive applications. The high level of interest in these devices stems from the several advantages they offer. From the business point of view they are attractive due to their promise of large financial gains, and from the technological point of view because they feature low power consumption, low manufacturing costs (due to the possibility of exploiting existing technological processes and infrastructures already developed for integrated circuit fabrication and batch fabrication), small dimensions
Introduction

and the possibility of integration with electronic read out circuits. On the other hand MEMS and MOEMS devices require more complex read out interfaces.

The work done during this three year Ph.D. can be divided into four main activities. The first activity has been the study of the ISIF platform, developed by the University of Pisa in collaboration with SensorDynamics AG as an effective solution to long time design architectural space exploration needed by the traditional platform based design flow and the study of design methodologies developed to meet the demand of short time-to-market, cost reduction, reliability, performance enhancements and increasing systems’ complexity. In this scenario, the second research activity has been the extension of the ISIF platform application space to high-voltage and high-current sensor applications. More in detail, a high-voltage PWM driver with programmable output current has been designed and integrated on silicon for a flow sensor application based on a MEMS hot-wire anemometer.

The third research activity has regarded the study and development of a new platform, named SD4K, able to interface new generations of MEMS and MOEMS and especially targeted to realize a projection display based on a scanning micromirror and three laser sources. This kind of application requires high-voltage and high-current capabilities as well as high computational power to cope with laser and micromirror driving and with video data stream elaboration. The last research activity has been the development of the analog blocks that are used to actuate the scanning micromirror. This last activity has required several steps in order to be carried out: the study of micromirror actuation issues, the development of a low cost test environment, based on laboratory measurements and FEM simulations, for measuring micromirror main parameters and the subsequent development of two micromirror models for high-level system simulations and for electrical simulations of the analog blocks that have been designed as last part of this research activity.

This dissertation is organized as follows: Chapter 1 presents MEMS and MOEMS devices, the main technological processes involved in their fabrication and their main applications in industry, automotive and consumer markets. Finally the chapter describes some of the main applications of these devices in different market fields, such as automotive, communications and optics.

Chapter 2 starts with an overview of requirements for the most common electronic sensor interface and then presents the state of the art of the design methodologies for sensor interfaces: the generic sensor interface concept (based on sharing the same electronic among similar applications achieving cost saving at the expense of area and performances
loss) and the Platform Based Design methodology which overcomes the drawbacks of generic sensor interfaces by keeping the generality at the highest design layers and customizing the platform for a target sensor achieving optimized performances.

An evolution of the Platform Based Design flow achieved by the implementation onto silicon of the ISIF (Intelligent Sensor InterFace) platform is therefore presented in Chapter 3. ISIF is a highly configurable mixed-signal chip, which allows designers to perform an effective design space exploration and to evaluate directly on silicon the system performances avoiding the critical and time consuming analysis required by standard platform based approach.

In Chapter 4, after a more detailed description of state of the art MEMS flow sensors, an application of the ISIF platform for the design and validation of a sensor system for water flow monitoring based on a hot-wire anemometer in MEMS technology is described. The ISIF approach has enabled a fast and accurate evaluation of the whole sensor system without time consuming system simulations needed in traditional approaches for architectural exploration. Finally the chapter deals with the design and the characterization of the high-voltage driver used in the flow sensor application described and that has allowed the integration of almost the whole measurement system on chip. The driver is able to provide a PWM current and features low sensitivity to temperature, supply-voltage and process spreads, requirements that are necessary to achieve higher performances in a flow measurement system.

Chapter 5 introduces the SD4K platform and the state of the art of MOEMS systems, focusing on their use in laser-based projection systems. The platform has been design to cover very challenging test-benches, like a laser-based projector system. In this way the platform is not only able to effectively handle the sensor but also all the systems that can be built around it, reducing the need for further electronics. A brief overview of the final application and of the system study performed to validate the design choice are presented. First the analysis of the target micromirror from its early development to the latest re-design is described. Micromirror package issues are also analyzed with particular focus about vacuum packages and their impact over voltage driving and laser diffraction. Then the chapter describes the equivalent electrical model of the micromirror and how it has been developed exploiting FEM simulations and laboratory measurements performed on the micromirror. A model of the MOEMS device is essential for the proper design of the read out electronics and to perform high-level system simulations. Finally a description of the analog and digital sections of the platform blocks is given, with a particular emphasis on the IP developed in order to grant
the highest grade of flexibility with the minimum area occupation.

Chapter 6 deals with the design and characterization of the high voltage driver for the actuation of the dual-axis scanning micromirror that is used in the projection display system. Finally some conclusions are drawn.