

Modeling, Design, and Verification for the Analog Front-End of a MEMS-Based Parallel Scanning-Probe Storage Device

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Abstract—We present an integrated analog front-end (AFE) for the read-channel of a parallel scanning-probe storage device. The read/write element is based on an array of microfabricated silicon cantilevers equipped with heating elements to form nanometer-sized indentations in a polymer surface using integral atomic-force microscope (AFM) tips. An accurate cantilever model based on the combination of a thermal/electrical lumped-element model and a behavioral model of the electrostatic/mechanical part are introduced. The behavioral model of the electrostatic/mechanical part is automatically generated from a full finite-element model (FEM). The model is completely implemented in Verilog-A and was used to co-develop the integrated analog front-end circuitry together with the read/write cantilever. The cantilever model and the analog front-end were simulated together and the results were experimentally verified. The approach chosen is well suited for system-level simulation and verification/extraction in a design environment based on standard EDA tools.

Index Terms—Analog integrated circuits, integrated circuit modeling, MEMS interface circuits, model-order reduction, multidomain modeling, nanotechnology, sensor interface circuits.

I. INTRODUCTION

ULTRAHIGH storage densities of 1 Tb/in² or higher can be achieved by using local-probe techniques to write, read back, and erase data in very thin polymer films. The thermomechanical scanning-probe-based data-storage concept, internally dubbed “millipede” [1], [2], combines ultrahigh density, small form factor, and high data rates. High data rates are achieved by parallel operation of large 2-D arrays with thousands of micro/nanomechanical cantilevers/tips that can be batch-fabricated by silicon surface-micromachining techniques. Fig. 1 illustrates the “millipede” concept.

The high precision required to navigate the storage medium over the probe tips is achieved by MEMS-based x/y actuators that position the large arrays of probe tips for parallel write/read/



Fig. 1. The “millipede” concept.

erase operations. Thermomechanical writing is achieved by applying a local force through the cantilever/tip to the polymer layer and simultaneously softening the polymer layer by local heating. To read the written information, the same cantilever is used to scan the surface. The change in the thermal flow between a second heating element and the medium surface leads to a change in the electrical resistance of the heating element (see Fig. 2) [3].

The parallel operation of hundreds of cantilevers makes the CMOS integration of the analog front-end (AFE) imperative. To this end, a 3-D assembling technology has been developed to transfer the cantilevers onto the CMOS read-out circuitry [4]. The small relative resistance change ($\Delta R/R < 10^{-5}$ for a typical indentation) renders the design of the AFE’s read-channel a challenging task. This paper describes the design of the critical input stage of the read-channel based on co-simulation of the AFE circuitry and a multi-domain cantilever model. The resulting read-channel is the centerpiece of a 32-channel AFE chip [5]. Section II of the paper focuses on the model of the cantilever and Section III presents its experimental verification. Section IV gives the details on the model-based design and optimization of the critical first stage in the read-channel. Experimental results obtained with the complete 32-channel chip that was wirebonded to a cantilever array are also shown. Section V summarizes the paper.

II. VERILOG-A CANTILEVER MODEL

The AFE for the thermomechanical storage device is in essence a transducer interface circuit. As described above, information is stored in the mechanical topography of a thin polymer film. The micromechanical cantilever acts as a transducer to convert topographical variations into electrical energy during the read process, and vice versa during the write process.

Manuscript received November 11, 2006; revised March 4, 2007. The work of J. Lienemann was supported in part by the DFG project MST-Compact (KO-1003/6) and an operating grant of the University of Freiburg (Germany).

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Digital Object Identifier 10.1109/JSSC.2007.900287

Modeling And Verification Of Parallel Processes

Roy Leventhal, Lynne Green



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nite the state space traversal will eventually terminate with a definite verdict on the property that is being validated Equally helpful is the fact that in case the property is invalidated the model checker will return a counterexample a feature that greatly facilitates fault identification On the downside the time it takes to obtain a verdict may be very long if the state space is large and the type of properties that can be validated is restricted to a logic of rather limited expressiveness

Model Checking Software Dragan Bosnacki, Stefan Leue, 2003-08-01 The SPIN workshop series brings together researchers and practitioners interested in explicit state model checking technology as it is applied to the verification of software systems Since 1995 when the SPIN workshop series was instigated SPIN workshops have been held on an annual basis at Montreal 1995 New Brunswick 1996 Enschede 1997 Paris 1998 Trento 1999 Toulouse 1999 Stanford 2000 and Toronto 2001 While the first SPIN workshop was a stand alone event later workshops have been organized as more or less closely related events with larger conferences in particular with CAV 1996 TACAS 1997 FORTE PSTV 1998 FLOC 1999 World Congress on Formal Methods 1999 FMOODS 2000 and ICSE 2001 This year SPIN 2002 was held as a satellite event of ETAPS 2002 the European Joint Conferences on Theory and Practice of Software The collocation of SPIN workshops with conferences has proven to be very successful and has helped to disseminate SPIN model checking technology to wider audiences Since 1999 the proceedings of the SPIN workshops have appeared in Springer Verlag's Lecture Notes in Computer Science series The history of successful SPIN workshops is evidence for the maturing of model checking technology not only in the hardware domain but increasingly also in the software area While in earlier years algorithms and tool development around the SPIN model checker were the focus of this workshop series the scope has recently widened to include more general approaches to software model checking Current research in this area concentrates not so much on completely verifying system models

but rather on analyzing source code in order to discover software faults

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Enterprise and Organizational Modeling and Simulation Joseph Barjis, Robert Pergl, Eduard Babkin, 2015-10-12 This book constitutes the refereed proceedings of the 11th International Workshop on Enterprise and Organizational Modeling and Simulation EOMAS 2015 held at CAiSE 2015 in June 2015 in Stockholm Sweden EOMAS was founded with the purpose to become a forum among researchers and practitioners to share their research and practical findings by encouraging the dissemination of research results under a more generic umbrella called enterprise engineering which encompasses internal factors ranging from organizational complexity to intricacy of business processes and sophistication in workflows as well as external factors and uncertainties such as competition politics or the emergence of innovative technologies The 15 papers presented in this volume were carefully reviewed and selected from 28 submissions They were organized in topical sections

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Testing and Validation of Computer Simulation Models David J. Murray-Smith,2015-10-08 This must read text reference provides a practical guide to processes involved in the development and application of dynamic simulation models covering a wide range of issues relating to testing verification and validation Illustrative example problems in continuous system simulation are presented throughout the book supported by extended case studies from a number of interdisciplinary applications Topics and features provides an emphasis on practical issues of model quality and validation along with questions concerning the management of simulation models the use of model libraries and generic models contains numerous step by step examples presents detailed case studies often with accompanying datasets includes discussion of hybrid models which involve a combination of continuous system and discrete event descriptions examines experimental modeling approaches that involve system identification and parameter estimation offers supplementary material at an associated website **Semiconductor Modeling:** Roy Leventhal,Lynne Green,2007-01-10 Semiconductor Modeling For Simulating Signal Power and Electromagnetic Integrity assists engineers both recent graduates and working product designers in designing high speed circuits The authors apply circuit theory circuit simulation tools and practical experience to help the engineer understand semiconductor modeling as applied to high speed digital designs The emphasis is on semiconductor modeling with PCB transmission line effects equipment enclosure effects and other modeling issues discussed as needed The text addresses many practical considerations including process variation model accuracy validation and verification signal integrity and design flow Readers will benefit from its survey of modeling for semiconductors packages and interconnects along with usable advice on how to get complex high speed prototypes to work on the first try Highlights include Presents a very complete and well balanced treatment of modeling of semiconductors packages and interconnects Facilitates reader comprehension of the whole field of high speed modeling including digital and RF circuits Combines practical modeling techniques with the latest EDA tools for simulation and successful high speed digital design Facilitates resolution of practical every day problems Presents modeling from its historical roots to current state of the art Facilitates keeping abreast of the latest modeling developments as they continue to unfold Noise and Vibration Control on Ships

Raymond Fischer, Leonid Boroditsky, 2024-06-29 This book provides a guide for the marine community to understand and address the noise and vibration environment associated with ships. Controlling noise and vibration in an effective and optimal manner requires a comprehensive understanding of all the ship systems that are involved in achieving a quiet vessel. While there are numerous published articles addressing various components of shipboard noise and vibration, this represents the first comprehensive book on the subject. Beginning from the basic acoustics of noise and vibration, it builds to more complex considerations in undersea sound, ship design, and compliance. The book provides an understanding of the source-path-receiver modelling of shipboard noise and vibration. It delivers an overview of how to select and optimize both noise and vibration control treatments along with design guidance and methods to demonstrate compliance with acoustic regulations. It reflects the knowledge gained by the authors consulting over 40 years each on hundreds of vessels and represents an invaluable resource for ship builders and marine engineers.

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