CAD of Microsystems - A Challenge for Systems Engineering

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ABSTRACT

Designing, verifying and testing microsystems and microsystem-components will not be feasible without the intensive use of design methodologies and supporting computer aided design tools. Requirements Engineering at the beginning of a top down design flow results in formal specifications for the desired system and component behavior and a list of design constraints. These are the basis for documentation as well as for modeling, system simulation, parameterized component design and hardware/software-codesign. Finite Element Analysis and simulations on various levels of abstraction are necessary to characterize parameterized functions (e.g. sensors and actuators built on different microtechnologies and materials) and generate macromodels in a bottom up design flow to verify each design step for component integration, system integration, packaging and interconnects, especially dealing with parasitics and cross sensitivities.

Extended Abstract

Highly innovative applications for microelectronic components e.g. in automotive and industrial control systems, measurement systems, communication equipment and medical equipment as well as some consumer electronics show an increasing demand for system integration. True system integration means integrating a complete system (e.g. an internal cardiac pacemaker) or a large part of a system in a single integrated circuit, a small ceramic substrate or flexible printed circuit board housed in an application specific formed package with adapted interconnects to its environment, thus incorporating not only digital functions but also analog functions as well as various sensors and actuators. Microsystem technology introduces new ways for realizing miniaturized, intelligent, flexible and adaptive systems, in other words "smart systems", to be used as embedded systems typically for measurement and control functions. The microsystem is always part of a larger system with interconnects for energy, material and information. At the interface biological, chemical or physical signals are carried in energy forms (radiation, mechanical, thermical, magnetical, optical) which are converted by sensors into electrical signals, which after being conditioned by microelectronic interface circuits will be processed either in analog or preferably in digital form. Signal processing, overall system control and system communication is mainly done by digital signal processors and microcontrollers running a real time operating system. The microsystem is acting back into its environment via actuators, which convert electrical signals into other signal carrying energy forms. Those actuators very often need some kind of power electronics and of course the whole microsystem needs an energy supply which usually is a critical part of the design too (e.g. battery powered or wireless energy transmission). Tough operating conditions in a harsh environment (automotive, incorporate medical) is another typical constraint for microsystem design.

To summarize, microsystems are characterized by the optimized application of "microtechnologies" and "systems engineering concepts". Microtechnologies, e.g. microelectronics, micromechanics and microoptics are those fabrication technologies which enable miniaturization. Packaging and interconnect technologies enable the configuration of individual components, innovative concepts for system architectures and signal processing enable the integration and optimization of components into systems and finally the concepts of systems engineering allow for the complex design process by attaching methodologies and computer aided tools for planning, specification, modeling, simulation, design, verification and test.

Although the design of complex electronic control systems has been accomplished for many years the miniaturization and integration of mechanical and optical system-components results in decreased system dimensions and increased system compaction thus mandating the consideration of parasitic effects and device interactions (e.g. dependencies of actuator or sensor characteristics on thermal coupling with digital or analog blocks with high

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power dissipation, electromagnetic compatibility (EMC) and more general biological, chemical and physical compatibility (BCPC) as well as reliability issues of safety related systems such as pacemakers or automotive ABS). These interactions and the complexity of both system and system-components mandates an exhaustive use of CASE/CAE/CAD/CAT/CAxx tools.

To obtain an optimized system where the system is greater than the sum of the components microsystem design means dealing with system design on a very abstract level, with component design on a very detailed level close to manufacturing technologies, with packaging and interconnect technologies as well as with parasitics and cross sensitivities.

The systems engineering process of planning, doing mission and functional analysis, trade-off studies, baseline system definition and requirements specification form the basis for design, modeling, simulation, validation, verification, integration, test and characterization, fabrication and maintenance to be done hierarchically on system level, subsystem level as well as on components level using a meet in the middle strategy.

Today a large variety of very powerful domain specific computer aided design, simulation, analysis and test tools provide support for the development of components, e.g. digital and analog microelectronics, software, mechanical sensors and actuators or optical components. Also there are some system level design and analysis tools available. However, these are individual tools (point tools), there are no or few interface standards, no common data bases, no common user interfaces and there exist some gaps for important design steps especially in early system design phases (requirements engineering, trade-off studies, performance estimation, cost estimation etc.). Due to the complexity of microsystem design, we believe that there will be no single integrated design system existing capable of handling all requirements for designing and verifying the complete microsystem as well as all possible system-components and packaging and interconnects. Therefore, we suggest a "meet in the middle strategy" for design environments on three levels: system level, integration level and component level.

A environment for overall microsystem design will include methodologies and tools which support the system engineers in project and tool planning, mission and functional analysis, requirements engineering, estimating critical economical and technical design data, doing hardware/software trade off and performance analysis for the evaluation of design alternatives, and preparation for hardware synthesis, simulation, test and diagnosis. The tools should be highly productive, resulting in short conceptual design cycles by supporting reusable hardware and software modules and allowing a vendor and technology independent design as long as possible. The final outcome will be a project management plan, a development and test specification and a design review plan. In a top down approach, these data is handed over to the component design environments.

Design environments for components are characterized by tight coupling to certain technologies and vendors, the tools will be dedicated but highly flexible and will only be used by experts knowing the details of the underlaying technological and manufacturing processes, they will support component optimization and characterization and shall result in quality assured parameterized component libraries or a single component optimized for a specific system.

In a bottom up approach feasibility data, component design alternatives, characterized data, macromodels, reliability data etc. is handed back into the system design environment. Systems engineers and component engineers meet in the middle in a cooperative, concurrent design process, joined by engineers and a design environment dealing with system integration, packaging, interconnects as well as parasitics and cross sensitivities. Thus, the design of microsystems mandates an open and flexible integration platform that provides design flow management, common data management and a common graphical user interface to support the various design environments..

The simulation of microsystems and microsystem components is one of the most demanding tasks for validation and design verification. The consideration of complex sensitivities crossing the electrical, the thermal, the optical and mechanical domain provides one of the major problems for the simulation of microsystems. The modeling of such interactions demands interdomain expert knowledge and powerful modeling languages. Typically, complex designs are described on different levels of abstraction, on discrete as well as on continuous quantities, solving boolean equations, ordinary differential equations up to multidimensional partial differential equations. Thus mixed-mode/multi-level simulators are needed not only for design verification and validation but also for design optimization, characterization and design for testability issues. Especially the design of sensor or actuator arrays are very demanding with respect to simulation.

Finally, highly sophisticated diagnostic tools need to be developed for prototype test, quality assurance, production test, field maintenance test and fault diagnosis purposes.

Various examples for design methodologies and design tools used will be given during the talk discussing specification, modeling, design, simulation and test of a miniaturized electro-chemical analysis system and a micropump as one of its key components as well as an intelligent microoptical sensor for measurement of speed, length and vibration of moving surfaces.