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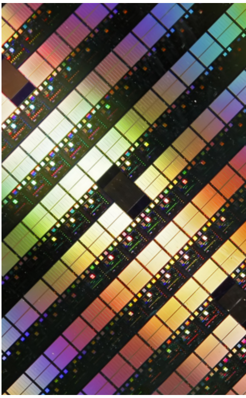

DATE 15

Design, Automation and Test in Europe

CONFERENCE & EXHIBITION

March 9–13, 2015, Grenoble, France

Range Based Analysis of Inner Systems Characteristics

(Extended abstract for the EDAA/ACM SIGDA PhD forum at DATE 2015)

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INTRODUCTION - Technology development is increasingly driven by "smart" device characteristics. Thus, the functional density rises, which correlates with a continuous decrease of silicon structural sizes. With the concequence that variations of circuit parameters and component characteristics develop an increasing impact on the full system behavior. A major research topic of this thesis is an enhanced system analysis considering stochastic range inputs. Proposed analysis techniques evaluate whether specified uncertainties may influence the intended behavior and drive the system into unspecified states. As described, uncertainties are superimposed on input signals or describe variations in model parameters. For analysis and simulation I use a semi-symbolic approach to describe these uncertainties in an abstract way. This semi-symbolic modeling enables new capabilities in enhanced simulation and analysis techniques.

CHALLENGES AND TASKS - Based on SystemC and its AMS extension, this work focuses on techniques considering uncertainties at the system's inputs. These uncertainties can be caused by process variations and manufacturing abnormalities, deviated analog signals, functional disturbances, signal jitter in time and frequency domain, etc. [1]. Accordingly, uncertainty values may have their origin in the analog as well as the digital domain [2]. Caused by the strong functional interaction of analog and digital parts, uncertainty effects may be correlated across domains.

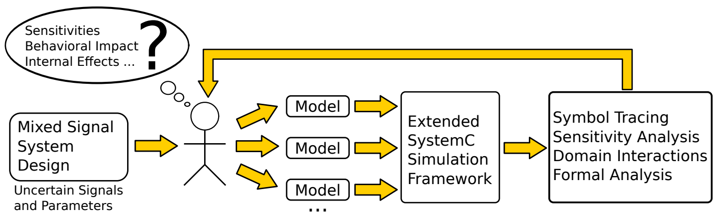

Fig. 1. A verification engineer is interested in an enhanced insight into a system design which is stimulated by uncertain inputs. Proposed analysis techniques enable optimization processes to adjust signal sensitivities, monitor internal deviation effects, analysis of uncertainty interactions, etc.

Figure 1 depicts an abstracted system simulation and analysis sequence. A human verification engineer intends to verify and evaluate potential optimizations of a mixed-signal system design. A central condition of this verification process is that input signals and parameters of the system deviate from the ideal value. Verification and analysis goals deal with questions regarding the inner characteristics of the system under test (e.g. signal sensitivities with respect to input deviations, behavioral correctness inside the range of tolerances, internal uncertainty gaining or attenuation effects, etc.) Then a set of models is transformed or deduced from the initial (exact) design. These models are simulated under consideration of the defined uncertainties. Finally, range based analysis techniques are applied on the resulting simulation outputs. The increased internal knowledge and insight closes the loop by refinement and optimization of the original design. As a result, range based analysis may raise the robustness of the design, guarantee correct behavior under specified signal tolerances (safety properties) and may guide design optimization.

EXTENDED SIMULATION ENVIRONMENT - For the representation of uncertainties a semi-symbolic calculation methodology based on Affine Arithmetic is used. Abstract symbols describe deviation intervals which are located symmetrically around the central (exact) value [3] [4]. This extends the classical numerical system simulation by symbolic characterization of uncertainty sources. Additional benefits in contrast to Monte-Carlo or corner case simulation are given by the computation of output signal ranges within a single simulation step [4]. Advantages, which enable the following proposed analysis processes, are defined by the representation of uncertainty correlations, tracing of symbols during simulation and description of deviation gaining as well as attenuation effects. An object oriented implementation of an Affine Arithmetic datatype and corresponding mathematical operations in C++ enables the integration within the SystemC AMS environment. Extended functionalities as deviation symbol management, tracing of uncertainties and application specific approximation algorithms are highlighted. Earlier published approximation techniques for nonlinear affine operations and an algorithm featuring exact interval bounds are discussed [5].

ANALYSIS TECHNIQUES - Advantages as tracing capabilities, localization of gaining and attenuation effects, sensitivity of input signals, etc. are an appreciable benefit during the design phase. In combination with the mentioned simulation and modeling techniques, bounds of operation may be derived before fabrication. The following analysis techniques have been developed.

Tracing of deviations and localization of hot spots: The module based representation of system components allow highlighting of dedicated execution paths through the system

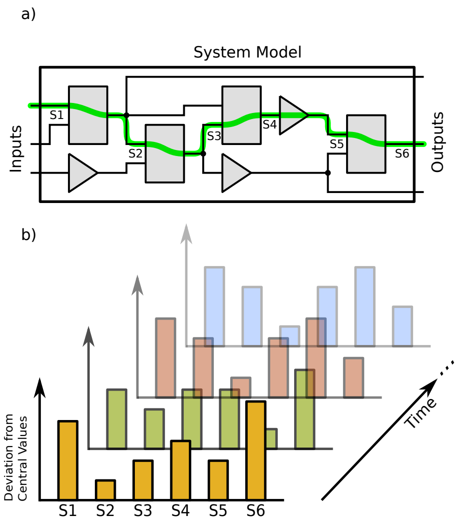

Fig. 2. a) Tracing of deviation values at a selected signal path trough a system model. b) Monitored time slices at each segment of a path which is the basis for further analysis.

as illustrated in Figure 2-a. A selected uncertainty, represented by a dedicated symbol can be inspected and recorded at each portion ($s1$ to $s6$) along the selected path. Monitoring deviation values of each single path segment over time, as indicated in Figure 2-b, allows an enhanced analysis if deviation values are gained or attenuated inside the circuit structure (e.g. caused by signal feedback loops). So called "deviation hot spots" in the circuit structure may be identified and optimized in a following design refinement process. To assess the impact of a selected path to system robustness, metrics such as signal to deviation matrices (similar to the commonly used signal to noise ratio) are defined [5], [6].

Sensitivity and stability analysis: The sensitivity of a signal represented by an Affine Arithmetic form is defined by the partial derivation with respect to a selected deviation symbol. Large sensitivity values with respect to a modeled uncertainty, cause large signal ranges at outputs. Another uncertainty impact can be analyzed in the temporal behavior of a deviation term at a selected path segment in the circuit. This is represented by the value changes at the illustrated time slices in Figure 2-b [7].

Hybrid domain interaction analysis: Correlations of uncertainty sources can be described by using equal formal deviation symbols. Thus, interactions between analog and digital functional blocks can be analyzed in detail. On the first side, specified analog value ranges may overlap one or more discretization steps at A/D conversion. On the other hand intervals described in the digital domain may have a direct impact on the control flow of the system. Hence, a major question is how these interactions and non explicit behavior can be handled during system simulation, and how analysis techniques contribute to verification processes.

Formal design analysis: In contrast to simulation based analysis, formal hardware verification results in a mathematical proof whether a specified verification goal is fulfilled within a pre-synthesized system model. The outcome of this approach is that inner characteristics of a circuit can be also specified in an unambiguous formal way [8]. Input values for a formal worst case analysis may result form previous simulation based analysis techniques. Counterexamples returned form formal verification tools may act as a starting point for detailed manual inspection of the design to find out whether inadequate behavior originates from design errors, security leaks, incomplete specification, or insufficient system robustness.

RESULTS AND CONCLUSION- Generally, results of this thesis are enhancements in range based analysis of mixed-signal systems. The results so far are:

- Simulation techniques to enable the integration of Affine Arithmetic forms into the SystemC environment [5].
- Tracing and enhanced analysis of signal deviations on a specified path (see Figure 2-a) [5], [9].
- Sensitivity analysis evaluating the influence of uncertain signal inputs to resulting signal ranges of corresponding outputs [6], [7].
- Formal system analysis and specification of system properties within a mathematical unambiguous formalism [8].

Future and ongoing work concentrates in extending analysis techniques for covering full mixed-signal behavior. The proposed analysis of hybrid domain interactions require a tight formalism in describing A/D and D/A conversions which is still work in progress. It is expected that consideration of uncertainties in parameter and signal values may become a valuable co-existing technique to conventional state of the art (numerically exact) analysis methods on system level.

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ACM SIGDA / EDAA PhD Forum at DATE 2015 in Grenoble

The ACM SIGDA / EDAA PhD forum is part of the DATE Conference and hosted by ACM SIGDA and the European Design Automation Association (EDAA). It offers the opportunity for PhD students to present their thesis work to a broad audience in the design, automation and test community from academia and industry. During the presentation at the DATE Conference, it helps students to establish contacts. Also, representatives from industry and academia get a glance of state-of-the-art research in design, automation and test. The review process resulted in the selection of the PhD students listed below. We thank ACM SIGDA, EDAA, and DATE for making this Forum possible.

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Range Based Analysis of Inner Systems Characteristics

Michael Rathmair
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Abstract – The design of embedded systems faces new challenges in increasing functional density and decreasing silicon structural sizes. With the consequence that variations of circuit parameters, input signals, manufacturing processes, etc. from its ideal may cause an increased parasitic impact on the full system behavior. The main research topic within this work is range based simulation and analysis of electronic designs where system parameters are superimposed by random uncertainties.

Introduction and Motivation

Variations in circuit parameters and model characteristics have to be **considered from a very early stage** in the design process.

Uncertainties may be caused by:
→ Abstraction of models
→ Process variations and manufacturing abnormalities
→ Deviated signals (time/frequency domain, analog/digital)
→ Unspecified user operation, etc.

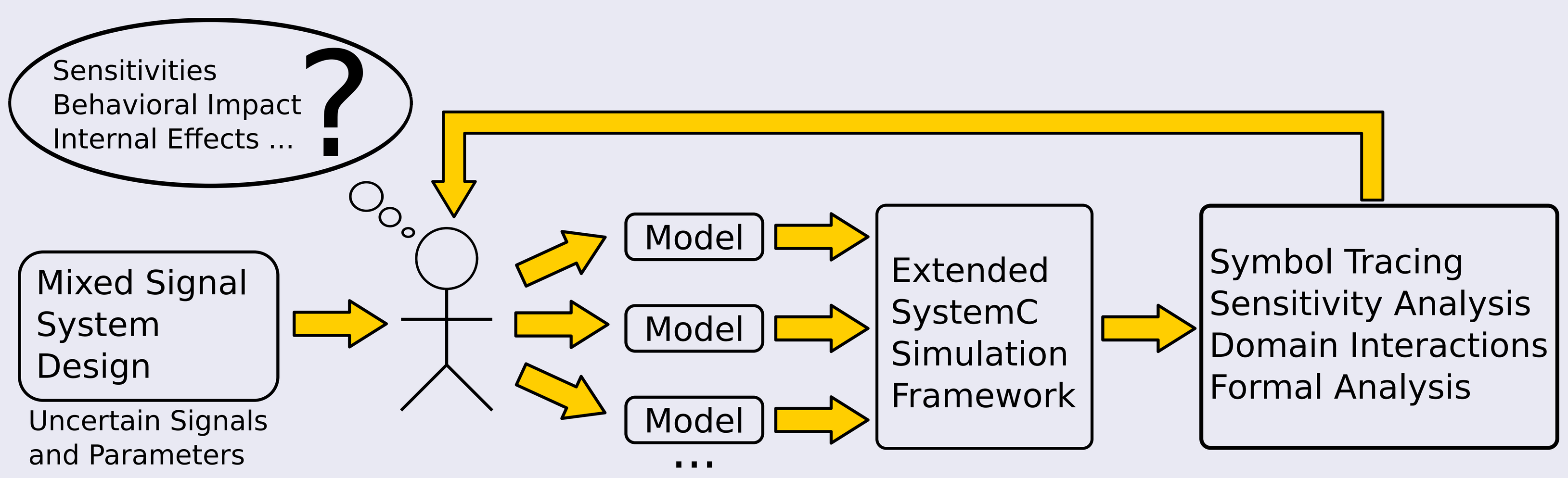

Figure 1 : Simulation and verification flow under the consideration of uncertainties

- Input signals and parameters of a mixed signal system design **deviate from their ideal values**.
- Uncertainties are covered in a set of **semi-symbolic models** deduced from the initial (exact) design.
- The SystemC AMS simulation framework interprets the models and simulates the full system.
- **Range based analysis techniques** are applied on the resulting simulation outputs.
- Evaluation of **inner system characteristics** (*e.g. signal sensitivities, behavioral correctness, internal uncertainty gaining or attenuation effects, etc.*)
- Results may increase the **robustness** of the design, guarantee correct behavior under specified signal tolerances (**safety properties**) and guide design **optimization**.

Extended Simulation Environment

Affine Arithmetic is used for formal representation. Each abstract symbol ϵ_i represents a specific uncertainty cause.

$$\hat{x} = x_0 + \sum_{i \in \mathcal{N}_{\hat{x}}} x_i \epsilon_i$$

with $x_0 \in \mathbb{R}, x_i \in \mathbb{R}, \epsilon_i \in [-1, 1], i \in \mathcal{N}_{\hat{x}}, \mathcal{N}_{\hat{x}} = \{i \in \mathbb{N}^+ | x_i \neq 0\}$

- Output ranges of the model are computed **within a single simulation step**.
- **Correlation** of uncertainty causes can be described.
- Description of deviaiton **attenuation and gaining effects** (x_i can be either positive or negative).
- Extended functionalities as **symbol management**, **tracing** of uncertainties and application specific **approximation algorithms**.

Analysis Techniques

Based on advantages and enhanced capabilities of the simulation environment the following analysis techniques have been developed.

Tracing of deviations and localization of hot spots

- Selection of a dedicated execution path/trace through the system. $\tilde{t} = \{\hat{s}_1, \hat{s}_2, \hat{s}_3, \hat{s}_4, \hat{s}_5, \hat{s}_6\}$
- Inspection and monitoring of a deviation at each segment ($s1$ to $s6$) along the selected path $\tilde{t}$ (Fig. 2a). $\{x_i[s1] \ldots x_i[s6]\}$, $i \in \mathcal{N}_{\hat{s}_1}, \ldots, \mathcal{N}_{\hat{s}_6}$
- Monitoring specific deviations of each execution path segment over time (Fig. 2b). $\{x_i[s_j](t), x_i[s_j](t-1), \ldots, x_i[s_j](t-n)\}$, $j = 1 \ldots 6$

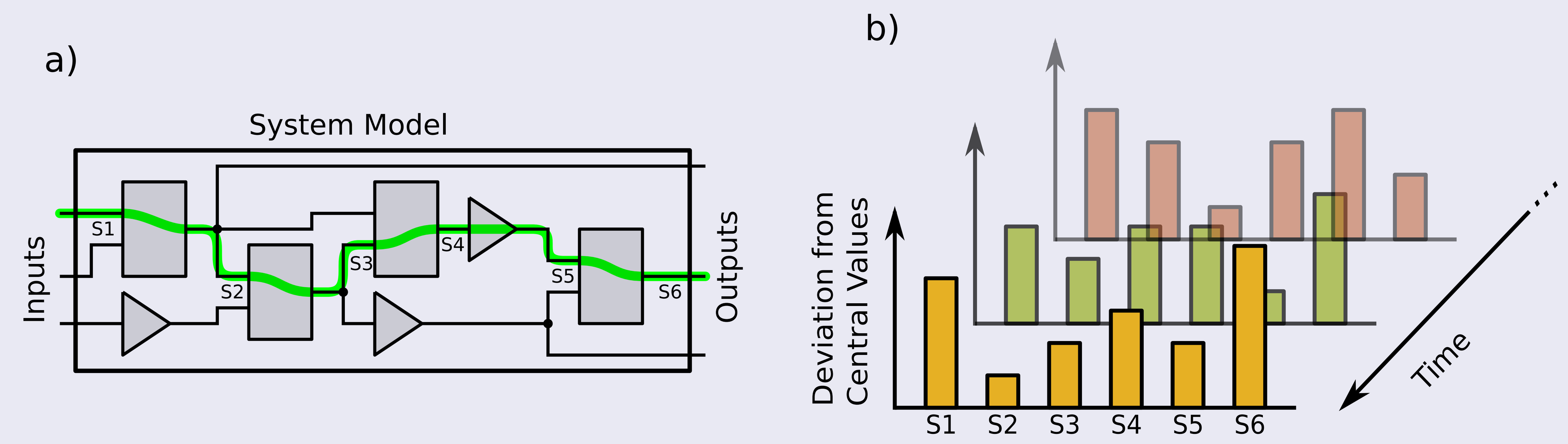

Figure 2 : a) Tracing of deviations at a selected execution path b) Analysis of deviations at selected time slices.

Sensitivity and stability analysis

- Defined by the partial derivation with respect to a selected deviation symbol $\partial\hat{x}/\partial\epsilon_i$.
- Analysis in **temporal behavior of a deviation term** at a specific path segment inside the system. $\|x_i[s_j](t) - x_i[s_j](t-1)\|$

Hybrid domain interaction analysis

- **Correlations** of uncertainty causes can be described by **multiple integration of symbols** in various Affine Arithmetic forms.
- Value and time discretization at A/D conversation.
- **Impact of control flow statements** on range representations.

Formal design analysis

- Proof whether a set of **formally specified characteristics** $\{p_1, p_2, p_3 \ldots\}$ is fulfilled within a pre-synthesized system model $M \models \{p_1, p_2, p_3 \ldots\}$.
- The system is formally analyzed at specified **corner case operating conditions**.
- Counterexamples returned form formal verification tools may act as a starting point for detailed manual inspection and optimization of the design.

DATE PhD Forum 2015 Reviews for Submission #26

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Title: Range Based Analysis of Inner Systems Characteristics

Authors: Michael Rathmair

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REVIEWER #1

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Reviewer's Scores

Quality: 3
Presentation: 3
Overall: 4

Comments

This thesis proposes analysis techniques to study the behavior of an analog mixed system under uncertain inputs. The proposed techniques are coupled to a simulation environment which is also presented in this work. Overall, the work presents an interesting contribution in this field. The thesis is supported by various publications in top-level conferences.

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REVIEWER #2

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Reviewer's Scores

Quality: 3
Presentation: 4
Overall: 3

Comments

This work presents a framework for system analysis with consideration of uncertainties posed on both input signals and model parameters. The research summary is well-written with interesting results. To make the proposed research stronger, this reviewer would make the following two suggestions. First, it is important to describe how to extract the uncertainties from a given system design. Second, the author is encouraged to think about the fundamental algorithm challenges in this area and then propose a number of new algorithms to address these challenges.

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REVIEWER #3

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Reviewer's Scores

Quality: 3
Presentation: 3
Overall: 3

Comments

This research topic is interesting, but the abstract is not very clear about the exact contributions. Additionally, it does not give any results or clear conclusions highlighting the impact of the proposed contributions.