

Application-driven Post-Silicon Verification of Automotive Smart Power ICs

Applikations-orientierte Laborverifikation von Automotive Smart Power ICs

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Kurzfassung

Steigende Komplexität und höhere Integration von Automotive Smart Power Mikroelektronik erfordert eine Verbesserung der Schaltungsqualität. Neue Richtlinien bezüglich Funktionalität und funktionaler Sicherheit führen dazu, dass sich deren Verantwortung zunehmend vom Zulieferer in Richtung des Halbleiterherstellers bewegt. Eine höhere Schaltungsqualität erfordert neue und verbesserte Verifikationsmethoden um die Funktionalität und die Leistung der analogen und mixed-signal Schaltungen garantieren zu können. Traditionelle Verifikationsmethoden stellen primär den Beweis dar, dass die Spezifikation eingehalten wurde. Dieser Schritt ist notwendig aber lässt keine Aussage über die Funktionalität in der Applikation zu. Deswegen ist es wichtig die Tauglichkeit der Mikroelektronik in ihrer Applikation nachzuweisen.

Applikationstauglichkeit wird heutzutage während der simulativen Verifikation geprüft. Simulationsumgebungen ermöglichen einen hohen Grad an Flexibilität und Konfigurierbarkeit. Hierbei ist es möglich alle Parameter der Mikroelektronik und der einzelnen Applikationskomponenten zu verändern. Dennoch sind Simulationen mit Modellfehlern und einer limitierten Genauigkeit behaftet. Auf Grund der hohen Integration müssen die Modelle mehrere Abstraktionsebenen durchlaufen um mit dem Simulationsaufwand umgehen zu können. Dadurch werden einige physikalische Effekte (z.B. parasitäre Einflüsse) auf Applikationsebene vernachlässigt. Um die höchste Genauigkeit sowie Schwankungen in den Applikationskomponenten zu vereinen, muss die Applikationstauglichkeit zusätzlich in der messtechnischen Verifikation nachgewiesen werden.

Auf Grund der eingeschränkten Konfigurierbarkeit von Applikationsaufbauten lassen sich Applikationsparameter während Messungen nicht verändern. Ziel dieser Arbeit ist es, eine Methodik bereitzustellen mit der sich die Applikationstauglichkeit in der messtechnischen Verifikation von Automotive Smart Power ICs nachweisen lässt.

Hierfür wird ein allgemein gültiges Konzept bereitgestellt womit diverse elektrische Komponenten innerhalb der Automobilelektronik, wie Glühlampen, Elektromotoren oder Batteriezellen mit einem Emulator ersetzt werden. Dieser Applikationsemulator berechnet das dynamische, elektrische Verhalten der jeweiligen Applikationskomponente in Echtzeit und stellt die physikalische Größe an den Anschlüssen der mikro-elektronischen Bauelemente ein.

Diese Methodik ermöglicht es, während der messtechnischen Verifikation Einzelmessungen mit emulierten Applikationskomponenten durchzuführen und einzelne Applikationsparameter zu verändern. Mit Hilfe einer Laborautomatisierung wer-

den emulierten Einzelmessungen automatisiert ausgeführt um den sich ergebenden mehrdimensionalen Applikationsraum abdecken zu können. Dadurch wird das Systemverhalten unter verschiedenen Randbedingungen von Betriebszuständen und von Applikationsvariationen evaluiert und analysiert.

Basierend auf der Applikationsemulation und der Laborautomatisierung werden verschiedene Konzepte vorgestellt um Applikationstauglichkeit nachzuweisen. Ein Konzept bewertet Robustheit der Mikroelektronik mit Hilfe einer Mission Profile basierten Monte Carlo Analyse. Hierfür wird der Applikationsraum durch definierte Mission Profiles eingeschränkt und das Verhalten einzelner Systemparameter im Bezug auf deren Spezifikation analysiert. Das Verhalten wird mit Hilfe einer geeigneten Metrik quantifiziert. Das zweite Konzept beschreibt eine effiziente Worst-Case Analyse basierend auf Design of Experiment und Metamodel Methoden. Ziel der Methodik ist mit wenigen emulierten Experimenten, kritische Bereiche innerhalb des Applikationsraumes zu finden.

Die gesamte Methodik wird anhand einiger ausgewählter Beispiele aus der Automobilelektronik demonstriert und die Applikationstauglichkeit der Mikroelektronik unter Berücksichtigung von Applikationsvariationen nachgewiesen.

Abstract

Increasing complexity and high integration according to "More than Moore" strategies lead to a push for design quality of automotive smart power devices. Based on new concerns regarding functionality and functional safety, more responsibility moves from the supplier to the semiconductor manufacturer. An increase of the design quality requires new and improved verification methodologies to ensure functionality and performance of these analog and mixed-signal power devices. Classical verification methodologies focus on checking if the device is compliant to the specification. This check is a necessary step but provides no feedback about the correct functionality in the application. That is why the assessment of application fitness is required on top of classical compliance to the specification.

Application fitness is nowadays checked during pre-silicon verification. Simulation test benches enable a high degree of flexibility and customization to tune all parameters of the smart power device and the individual application components. However, simulations suffer from model imperfection and limited accuracy. Due to the high integration of automotive smart power devices, it is necessary to pass several abstraction layers to handle the simulation effort. Consequently, some physical effects (e.g. parasitic impacts) are neglected during simulations on the application level. In order to incorporate the full accuracy and variations of the application, it is necessary to assess application fitness during post-silicon verification.

Limitations of application test benches are related to the missing possibility to adjust all application parameters during measurements. That is why the objective of this thesis is the enabling of a methodology to assess application fitness during post-silicon verification of automotive smart power ICs.

Therefore, it is necessary to provide a general concept to replace physical automotive application components like incandescent light bulbs, electric motors or battery cells with an emulation system. This application emulator evaluates the dynamic, electrical behavior of the respective application component in real-time and adjusts the physical quantities at the electric terminals of the smart power device.

This methodology permits to execute single measurements with emulated application components and to adjust individual application parameters. By means of a measurement automation environment, it is possible to execute emulated measurements in an automated way and cover the resulting highly-dimensional application space. Accordingly, the system behavior is evaluated and analyzed under various conditions of environmental and application parameters.

On top of the application emulation methodology and the automation environment, several concepts for the assessment of application fitness are proposed. One concept evaluates device robustness by means of a mission profile-driven Monte Carlo analysis. Thus, the application space is restricted by mission profiles and the behavior of individual system responses is analyzed with respect to their specification boundaries. The behavior is quantified by means of an appropriate metric. The second concept describes an efficient worst-case analysis using Design of Experiments and metamodeling strategies. This methodology tends to find critical areas on the application space with minimum amount of emulated experiments.

The methodology is demonstrated by means of selected application examples in automotive electronics and application fitness of smart power devices is assessed under consideration of application variations.

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List of Acronyms and Symbols

ADAS	Advanced Driver Assistance System
ADC	Analog-to-Digital Converter
AFS	Advanced Front Lighting System
ASIC	Application Specific Integrated Circuit
BMS	Battery Management System
CAN	Controller Area Network
DAC	Digital-to-Analog Converter
DMOS	Double Diffused Metal Oxide Semiconductor
DoE	Design of Experiments
DSP	Digital Signal Processor
DUT	Device Under Test
ECU	Electronic Control Unit
ETC	Electronic Throttle Control
EV	Electric Vehicle
FPGA	Field Programmable Gate Array
HDL	Hardware Description Language
HEV	Hybrid-Electric Vehicle
HIL	Hardware-in-the-Loop
IC	Integrated Circuit
LIN	Local Interconnect Network
OEM	Original Equipment Manufacturer
PCI	Peripheral Component Interconnect

PHIL	Power Hardware-in-the-Loop
PID	Proportional-Integral-Derivative Controller
PXI	PCI eXtension for Instrumentation
WCD	Worst-Case Distance
XVP	eXecutable Verification Plan