Industry Best Practices in Reliability Prediction and Assurance for Power Electronics:
Part 1 - Reliability of Power Electronics Components

NAME AND AFFILIATION OF THE AUTHORS

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SCOPE AND BENEFITS

Reliability of power electronics becomes more and more important. There are several reasons for that:

- Renewable energy generation takes place in harsh environments, like off-shore or in deserts. Maintenance is complicated which means that systems have to operate failure-free for 20 years
- 30 years of failure-free operation is required for avionics and railways
- Advanced power devices like IGBTs and SiC devices can be operated at higher temperatures which means that the temperature swing increases. This creates higher mechanical stresses and fatigue

Based on the physics of failure mechanisms and lifetime prediction will be discussed.

CONTENTS

Monday, 5 September 2016 - Tutorial day (Location: KIT, Karlsruhe, Germany)

- 9:30 - 11:00	- Robustness Validation Process - - Reliability and Lifetime of Power Modules -	- E. Wolfgang - - M. Thoben
- 11:00 - 11:30	- Break -	-
- 11:30 - 13:00	- Reliability Testing of Power Devices and Modules - - Reliability and Lifetime of Passives -	- F. Heidemann - - - W. Wondrak

i) Robustness Validation Process

- The speaker will explain an approach how to secure reliability for power electronics systems and components which is based on the Robustness Validation process (SAE J1211 and AEC-Q101 Rev D1). The new standards will provide the automotive electronics community with a common qualification methodology to demonstrate acceptable reliability. It requires testing the component to failure, or end-of-life (EOL), without introducing invalid failure mechanisms, and evaluation of the Robustness Margin between the outer limits of the customer specification and the actual performance of the component. The reliability tests are based on mission profiles for specific applications, which include all stresses which are applied during operation for the whole specified life.

ii) Reliability and Lifetime of Power Modules

- Power Modules, used in e.g. hybrid electrical vehicles (HEV) and electric vehicles (EV), have to fulfil requirements that are strongly dependent on the mounting conditions, cooling system and operation strategy. The operation of today's power electronics is not limited by the chip technology itself but packaging technologies are suffering several wear out mechanisms, that are typically induced by thermal or power cycling.
- During the design phase of the inverter therefore not only the maximum operation temperature of the power electronics devices has to be determined, but also investigations on load cycling are required. The speaker presents approaches based on physics of failure Finite Element simulations and system level simulation to investigate the failure mechanism itself and the influence of the system design. The knowledge of application parameters, information of the power electronics components including thermal and electrical behaviour and a precise lifetime model for the failure mechanisms are essential.
- Influences of specific loads, effects of cooling concepts and several other application parameters will be discussed. Life time models are explained that are needed to compare thermal loads during the vehicle operation with results of accelerated tests. These tests are performed during the qualification e.g. according to the new the Qualification standard LV324, which also will be commented.

iii) Reliability Testing of Power Devices and Modules

Reliability Testing of Power devices is getting more and more a challenge and new semiconductor materials, architectures, testing standards and methods require new technical approaches to fulfil both customer and supplier needs today and in the future. Beside many others HTRB, HTGB, H3TRB, TDDB and HTOL as well as IOL and Power cycling testing are directly influenced by the increased device performance in terms of reduced size and increased operational voltage and current limits etc. and requires more flexibility and performance from dedicated test systems. During the session we will address the several challenges of these tests and discuss the different approaches based on real life examples and platforms from low level static test to high level dynamic tests e.g. single device temperature controlled tests to avoid thermal runaway.

iv) **Reliability and Lifetime of Passives**
Besides the power switches, the DC link capacitor is a key component in drive inverters. In the contribution, different capacitor technologies are presented and compared in terms of their application potential. In contrast to industry inverters, where Al electrolytic capacitors are generally employed, automotive industry focuses on polymer film capacitors. Ensuring the quality and lifetime of those components in the automotive environment is a non-trivial topic.
Whereas for electronic control units including power electronics, standardized environmental tests are performed, additional effort has to be spent on the device level. Integrated circuits, discrete power devices and small passive devices are requested to be qualified according to the AEC test standards AEC-Q 100, 101, and 200 respectively.
For power modules, e.g. those of drive inverters, a new automotive qualification scheme has been agreed on. Similarly, the existing AEC-Q200 standard does not cover the load profiles of an electric vehicle application (e.g. driving and charging), a new set of tests is under discussion in the ZVEI which shall enable to evaluate the principle capability of film capacitors for automotive inverters.
The criteria for those capacitors are:
- The capacitor is used in the DC link
- The capacitance is >100µF
- The voltage is >48V

The test scenarios and the test conditions are defined in accordance with the requirements on the power modules.

Part 2: Reliability Prediction and Assurance of Power Electronics Components

NAME AND AFFILIATION OF THE AUTHORS

Craig Hillman, DfR Solutions

SCOPE AND BENEFITS

The objective of the tutorial is to provide the attendees actionable information on the industry best practices on how to predict and ensure the reliability of power electronics. The tutorial will instruct attendees on electrical, thermal, and mechanical stresses experienced by power electronics, failure modes accelerated by these stresses, and tools and processes to predict degradation based on physics of failure models. Particular focus will be on degradation modes observed with wide band gap semiconductors (SiC and GaN).

CONTENTS

Monday, 5 September 2016 - Tutorial day (Location: KIT, Karlsruhe, Germany)

- 14:00 – 15:30	- Understanding Reliability Modeling of Power Electronics - Physics of Failure of Parts and Interconnects in Power Electronics (Part 1)	- C. Hillman
- 15:30 – 16:00	- Break	-
- 16:00 – 17:30	- Physics of Failure of Parts and Interconnects in Power Electronics (Part 2) - Case Studies and Examples of Physics of Failure and Design for Reliability in Power Electronics	- C. Hillman

v) Understanding Reliability Modeling of Power Electronics

- The speaker will provide a background and foundation regarding reliability modeling of power electronics. Will discuss understanding failure rate, including the historical and market drivers for current approaches geared towards empirical or accelerated testing. The speaker will present the fundamentals of physics of failure, including the base failure models and degradation modes of creep, fatigue, diffusion, and electro-migration.

vi) Reliability Physics of Failure of Parts and Interconnects in Power Electronics

- This section of the course will provide a thorough review of physics of failure model and approaches for technology relevant to today's power electronics. Topics that will be covered include
  - Capacitors
  - Magnetics
  - Solder Joints / Die Attach / Wire Bonds
  - Connectors
  - Circuit Boards
  - Electromigration / Diffusion
  - Compound Semiconductors (GaN, SiC)
  - Cosmic Rays (GTO, Thyristers, HV Diodes)
  - Optocouplers / LEDs

This section will conclude with a discussion on the process for implementing physics of failure prediction and risk mitigation into new product introduction process

vii) **Case Studies of Physics of Failure and Design for Reliability in Power Electronics**
This section of the course will present examples of the use of physics of failure and overall design for reliability during the front-end of the product development process and the resulting benefit

WHO SHOULD ATTEND

Young engineers and scientists who have to deal with reliability. Engineers involved in the design of board-level power electronics. This includes technology and component selection, layout design, mechanical packaging, thermal solution design, and reliability prediction.

Technical Level:

Knowledge in electrical engineering, material science, physics, testing and product requirements

ABOUT THE INSTRUCTORS

Prof. Dr. techn. Eckhard Wolfgang

Eckhard Wolfgang studied Mechanical Engineering and Technical Physics at the TU Vienna where he received the Dipl.-Ing. and the PhD degree. From 1970 until December 2006 he was employed by Siemens Corporate Technology at Munich. His main research topics were: Analytics, testing of Mbit DRAMs, power semiconductor devices and power electronics, reliability of electronic components and systems. 1994 he became Honoary Professor at the University of Dortmund, Faculty of Electrical Engineering.
He acted many times as technical chairmen of conferences like ESREF and CIPS. At present he works as a consultant for ECPE, the European Center of Power Electronics.

Dr. Ing. Markus Thoben

Markus Thoben received his diploma and PhD degree in electrical engineering from the University of Bremen, Germany in 1995 and 2002. From 1999 to 2004 he joined Daimler research institute in Frankfurt a.M., where he worked in the field of reliability and concepts for Power electronics and ECU-hardware. Since May 2004 he is employed by Infineon Technologies, Warstein in the development of Power Modules. Between 2008 and 2012 he headed the simulations group for Power Modules and technology development. Since February 2013 he’s in charge of the package and product development of Power Modules for electric and hybrid electrical vehicles.

Dipl.-Ing. Frank Heidemann

Frank Heidemann (Dipl. –Ing. (FH)) is Manager of the company SET GmbH with its headquarters in Wangen in the Allgaeu, which is specialised in testing systems for semiconductors and electronic components as well as the development and production of avionics. After his studies of Electrical engineering / Communications engineering at the University of Applied Science Weingarten and the Napier University Edinburgh, he was employed as a Developer at the company Telefunken Microelektronik and as a Project manager at the company Liebherr Aerospace. In 2001, Frank Heidemann was the cofounder of the company SET GmbH and since then he has been the Manager of the company which went to 80 employees in the meantime.

Dr. rer. nat. Wolfgang Wondrak

Wolfgang Wondrak is team leader for “advanced engineering of power electronics” at Daimler AG Group Research and development. He holds a Ph.D. in physics and worked on power semiconductor device technology and on SiC (silicon carbide) devices for high-temperature applications.

After some years on reliability aspects of semiconductor devices and passive components he is currently investigating power electronic solutions for future electric cars.

Dr. Craig Hillman

Dr. Craig Hillman is the Chief Executive Officer of DfR Solutions. DfR Solutions provides engineering services and tools that allow the electronic supply chain to meet customer expectations in regards to quality, reliability, and safety. Over the past seven years, Dr. Hillman has put together an a comprehensive group of subject matter experts in a number of different fields, including semiconductors, electronic design and fabrication, and systems engineering, and has overseen the release of the first Automated Design Analysis software to the EDA/CAE marketplace. DfR Solutions is now the largest organization of its kind in the world and has offices across North America and Europe. Dr. Hillman's specific expertise is in the development and incorporation of best-in-class product development processes that optimize existing resources and result in strong customer satisfaction. Dr. Hillman holds two patents, has over 100 publications, is a guest columnist for Global SMT & Packaging, has been a course instructor at IPC, SMTA, IMAPS and IEEE conferences, was identified by the US DoD as a subject matter expert in Pb-free technology, and has presented on a wide variety of quality and reliability issues to over 500 companies and organizations. He holds a B.S. from Carnegie Mellon in Metallurgical Engineering and Materials Science and Engineering and Public Policy and a PhD from University of California – Santa Barbara in Materials Science and received a research fellowship at Cambridge University in England