Munich, March 14, 2018
Eckhard Wolfgang

Summary of the ECPE Workshop "10 Years of Robustness Validation"
Leinfelden-Echterdingen, January 24 and 25, 2018

The first handbooks on Robustness Validation were available in the years 2006/07. They were worked out by the German ZVEI, the US SAE and the Japanese SAE.
They describe a process how to design, develop, manufacture and test electronic devices, components and systems. It is a process based on the knowledge of:
- the conditions of use (mission profile),
- the failure mechanisms,
- and of accelerated models needed for accelerated tests

This involves a paradigm shift from "test for standards" to "test-to-fail". The Physics-of-failure and End-of-life test approach requires a lot of new strategies and methods which will be discussed by industry as well as by Academia.
There were 4 Sessions and to underline the character of a workshop two Panel discussions dealt with:
- Design and Technology, and
- What about the future?

115 engineers and scientists attended the workshop which documents the importance of the Robustness Validation Process (RV) for industry.

At the beginning Eckhard Wolfgang (ECPE e.V.) introduced the basic question for the workshop to be discussed:

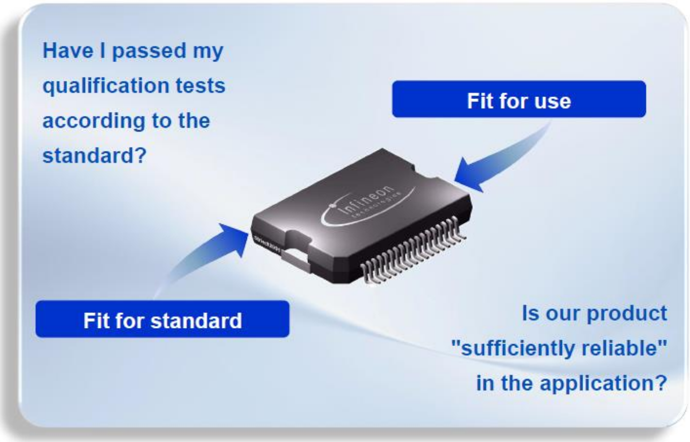

Fig. 1 The **basic question** for reliability engineering is: Is our product "sufficiently reliable" in the application? (Figs. 1 and 2 were designed by W. Kanert)

This calls for a knowledge based process:

Fig. 2 RV is a knowledge-based process

At the beginning Dr. Andreas Preussger (Preussger Consulting and former Infineon) introduced the history of reliability engineering and RV. The first conference on Physics of Failure (PoF) happened to be 1962 at the IEEE ITRS. In 2005 Helmut Keller started the international working group which resulted finally in several Handbooks published by ZVEI and SAE.

The new **'test to fail'** qualification approach (instead of a 'test-to-pass'), is a paradigm shift from **'Fit for Standard'** to **'Fit for Application'**.

Robustness Validation generates knowledge on the **relevant component failure mechanisms** that may occur at the boundaries of the specification limits.

Therefore Components could be designed with known **robustness margins** combined with cost and time saving potentials.

60 companies formed a task force to settle a new comprehensive Qualification method :

- ZVEI
- SAE
- AEC
- JSAE

Fig. 3 RV Handbooks:

https://www.zvei.org/en/subjects/mobility/robustness-validation-general/
An important step forward was the introduction of RV into the standards AECQ100 "FAILURE MECHANISM BASED STRESS TEST QUALIFICATION FOR INTEGRATED CIRCUITS"
http://www.aecouncil.com/Documents/AEC_Q100_Rev_H_Base_Document.pdf

and AECQ101 "FAILURE MECHANISM BASED STRESS TEST QUALIFICATION FOR DISCRETE SEMICONDUCTORS IN AUTOMOTIVE APPLICATIONS" [http://www.aecouncil.com/Documents/AEC_Q101_Rev_D1_Base_Document.pdf,](http://www.aecouncil.com/Documents/AEC_Q101_Rev_D1_Base_Document.pdf) which is valid for to single power devices. In both standards, the use of RV is described in Appendix 7.

Session 1: RV: Application Environment

10:50 **Reliability of Automotive LEDs** Wolfgang Pohlmann, Hella (D)
11:20 **Reliability of LEDs: Rth vs. Temperature – Impact on Lifetime Modeling** Stefan Schoemaker, OSRAM (D)
11:40 **Qualification Extension from Automotive to Harsh Aerospace Mission Profiles** Alberto Mancaleoni, STMicroelectronics (I)
12:10 **Comprehensive Methodology for Reliability Qualification of Smart Power Technologies** Antonio Andreini, STMicroelectronics (I)
12:40 **Synthetic Mission Profiles** Stefan Straube, Fraunhofer IZM (D)

Dr. Pohlmann explained how RV was used to develop a highly sophisticated front headlight with e.g. 84 LEDs in three rows.
The RV process is used for components optimization too.

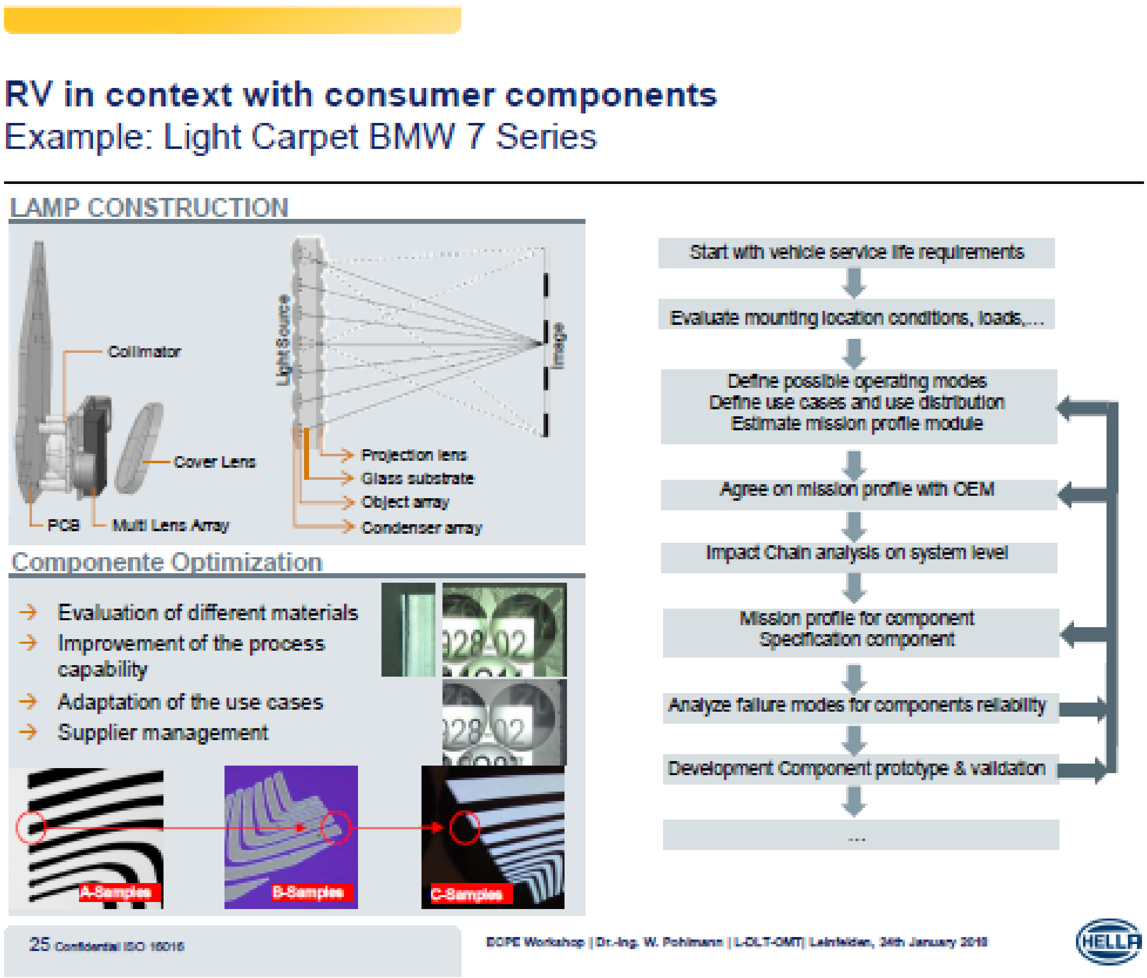

Fig. 4 Component opimization and RV process flow

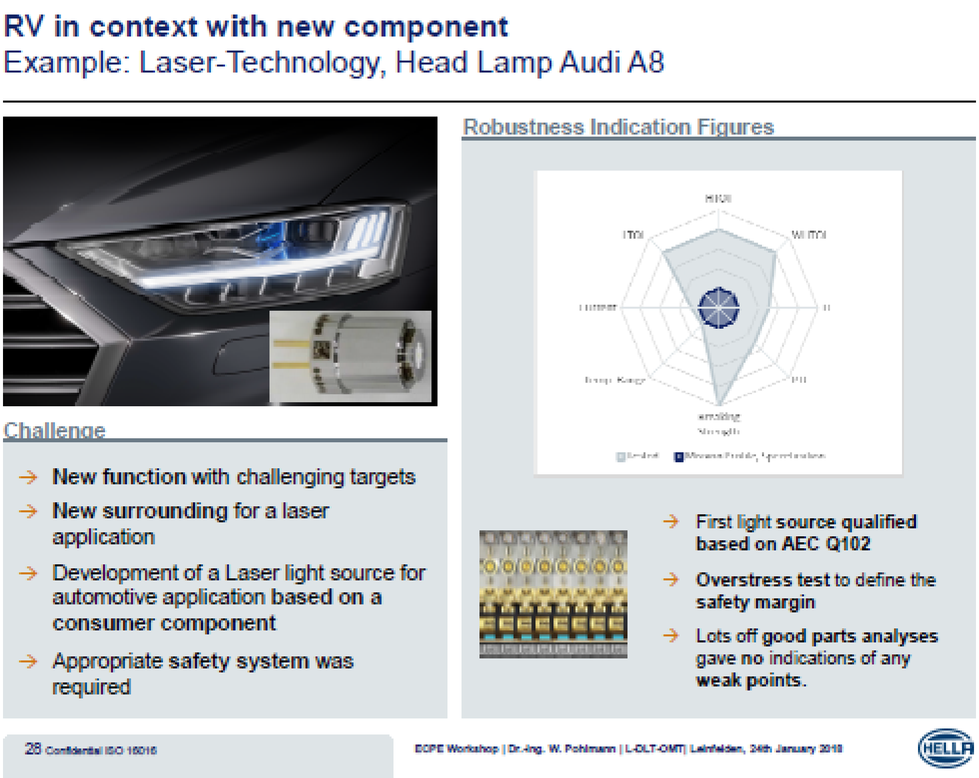

Fig. 5 Meaning and need for a Robustness Indicator Figure: Only if the robustness of a System/ Component/ Device is measured, is it possible to express the robustness figures and to compare different designs or different suppliers. Otherwise, robustness would just be a diffuse definition.

A. Mancealoni (STM) discussed the different requirements between automotive and aerospace industry. If a gap analysis is carried out, only a few additional tests for aerospace have to be done. This is process is called "GAP analysis".

ECPE

Experimental Results: Electrical Trials on Smart Power

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✓Equivalent analysis for smart power ICs (BCD9sL):

Trial	Conditions AEC-Q100 Grade 1	Device under qualification (Dut BCD)	Gap vs Airframe mission profile
HTOL JESD22-A108	1000hrs (1300hrs monitor) [Tj=160°C]	1000hrs: 0/77 x 1 (1300hrs: 0/77 x 1)	Q100 covers the mission profile NO GAP
LTOL JESD22-A108	100hrs [Ta=-40°C]	0/77 x1	During flight device will be at -55°C for 77khrs GAP present
ESD JESD22-A115 JESD-JS001 JESD22-C101	MM, HBM, CDM [200V, 2kV, 500/750V]	Passed	No specific requirements
LU JESD78	Current Injection, Supply Overvoltage [amb and hot]	Passed	NO GAP
ELFR JESD22-A108	BI+24hrs [Ta=125°C, Vcore+20%]	By similarity	No specific requirements NO GAP

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Fig.6 The LTOL test for aerospace applications calls for temperatures down to -55°C.

S. Straube (Fraunhofer IZM) presented a way how to generate synthetic mission profiles.

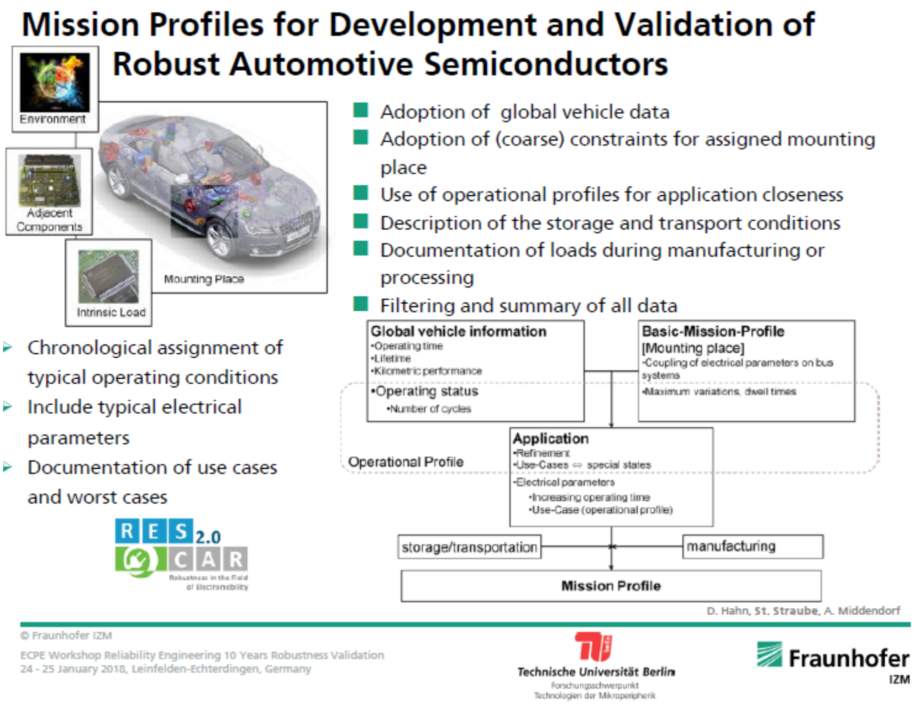


Fig. 7 OEMs are using their drive profiles normally in-house and are keeping them confidential.

Session 2: RV: Focus on Requirements and Technology

14:10 **Lifetime Modeling Strategies in the Context of Automotive Requirements**, Olaf Wittler, Fraunhofer IZM (D)

14:40 **RV in Context with AEC100/ 101 Appendix 7 Qualification** Ulrich Abelein, Infineon Technologies (D)

15:10 **Robustness Validation of Cu-wire in Semiconductor Devices for High Temperature Automotive Applications** Rene Rongen, NXP Semiconductors (NL)

O. Wittler (Fraunhofer IZM) explained the requirements from the OEM side and focused his presentation on modeling and simulation. His conclusions are:

- The trends involve
  - Increased power density / high functional integration
  - Increased operation time
  - New materials, technologies and concepts
- Current status
  - Lifetime models today address only standard modules and thermo-mechanical fatigue
  - Existing models may not be relevant for future technologies and use cases
- Future research needed on:
  - Identification on dominating failure mechanisms <-> mission profiles
  - Quantification of longterm effects (thermal ageing, (electro)chemical degradation, …)

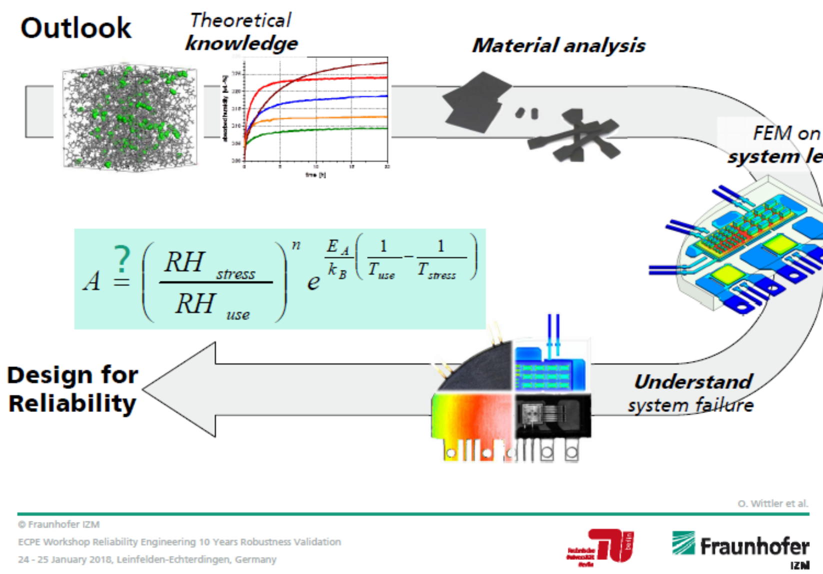


Fig. 8 Future outlook to get design rules for securing reliability of systems

U. Abelein (Infineon) explained the AECQ101 Rev D standard.
The test conditions, durations and sampling, however, may not be appropriate in case:

- Components in advanced technologies and or new materials are considered
- Application has a demanding loading profile
- Application has an extended lifetime requirement
- Application has a specific failure rate target over lifetime below the LTPD range

For this the Robustness Validation Process has to be applied.

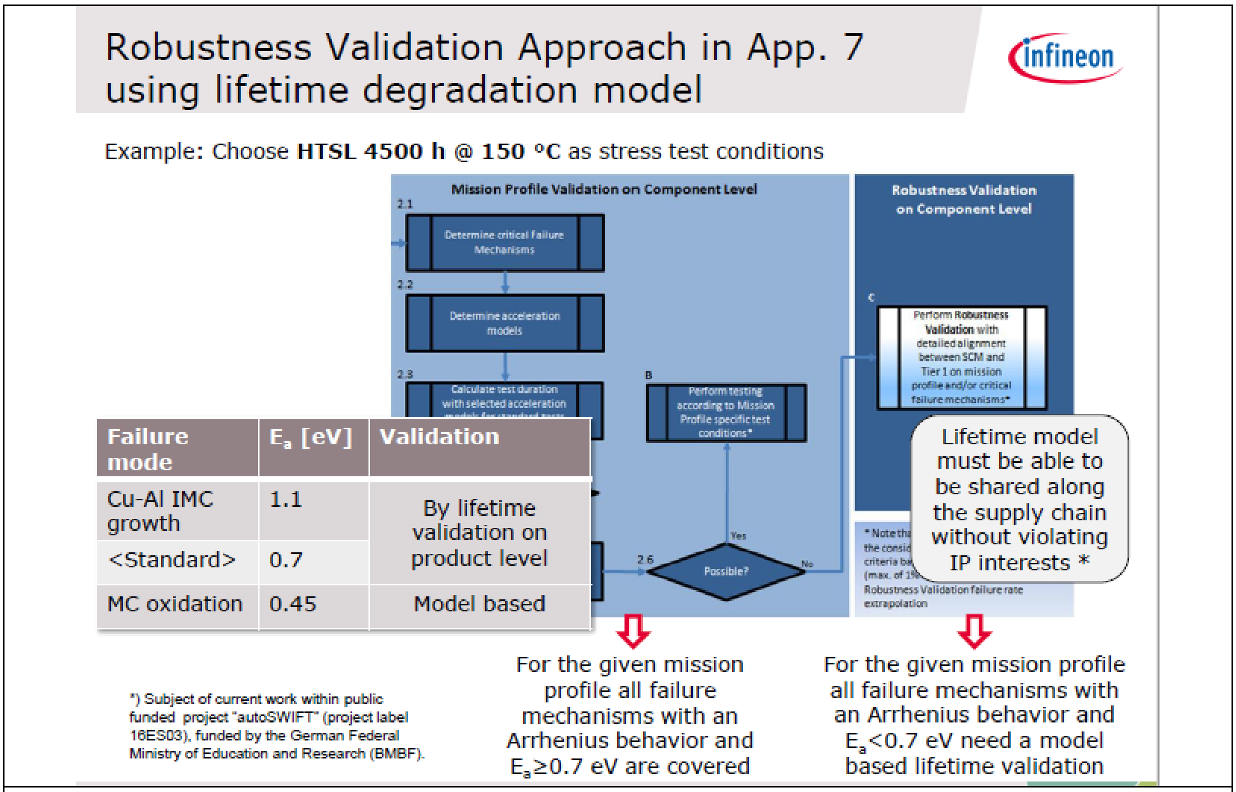


Fig. 9 AECQ101 Appendix 7:

R. Rongen (NXP) concluded:

- NXP has implemented Robustness Validation principles in new product and new technology releases since 2008
  - Supported by a structurally maintained reliability knowledge sharing infrastructure
- Understanding the Physics-of-Fail (PoF) and Physics-of-Degradation (PoD) is key to assess robustness margins
  - Analysis of the physical condition of pass devices (0h or after stress test) is needed and to be combined with electrical pass/fail criteria
- These principles have been demonstrated by assessing Cu-wire reliability for High Temperature Automotive Electronics
  - Ball shear lower spec limit will prevent from early fails due to ball bond lift
  - Large enough Intermetallic contact area at 0h will ensure large margin against ball bond lift at the end of use life

16 R. Rongen / Jan 2018 / External Use

Session 3: Power Modules and PE Systems

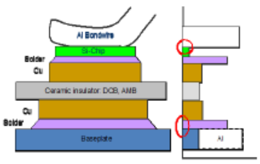
8:30 **Power Module an DC-Link Capacitor Qualification** Martin Rittner, Robert Bosch (D); Markus Thoben, Infineon Technologies (D); Kai Kriegel, Siemens (D)
9:00 **RV for Industrial Power Modules** Oliver Schilling, Infineon Technologies (D)
9:20 **Mission Profile and SiC Module Reliability** Francesco Iannuzzo, CORPE, Univ Aalborg (DK)
9:40 **Mission Profile Based System-Level Reliability Analysis of Power Electronic Converters** Huai Wang, CORPE Univ Aalborg (DK)

M. Rittner described the work done at two ZVEI-ECPE working groups to develop:

Identified Qualification Demand for the 'LV 324'

Instigated by the Robustness Validation Methodology:
Set of detailed qualification routines for automotive power modules

- List of all compulsory tests
- System definition: chip-near AIT and chip-distant AIT
- Environmental tests (incl. chip-distant characteristics)
  - Temperature-Shock-Test ('TST')
- Chip-near Power Cycling Test
  - In time region of seconds ('PCsek')
- Chip-distant (including chip-near portion) Power Cycling Test
  - Longing in time region of minutes ('PCmin')
- Semiconductor integrity
  - References to IEC 60747, IEC 60749 und IEC 60068
- Definition of relevant test parameters
  - Especially Rth/Zth
- Definition of End-of-Life criteria
- Description of testing procedure



Definition of chip-near AIT and chip-distant AIT

Division Electronic Components and Systems
Leinfelden, January 25th, 2018 – Slide 10

Fig. 10 Qualification of Power Electronics Modules for Use in Motor Vehicle Components. 6 modules per test are needed only.

The next version of the Power Module Qualification will be managed by ECPE to provide it for everybody who is interested in. The name of the new working group is AQG 324 which stands for Automotive Qualification Guideline. It will deal also with new technologies like SiC- and GaN- power modules.

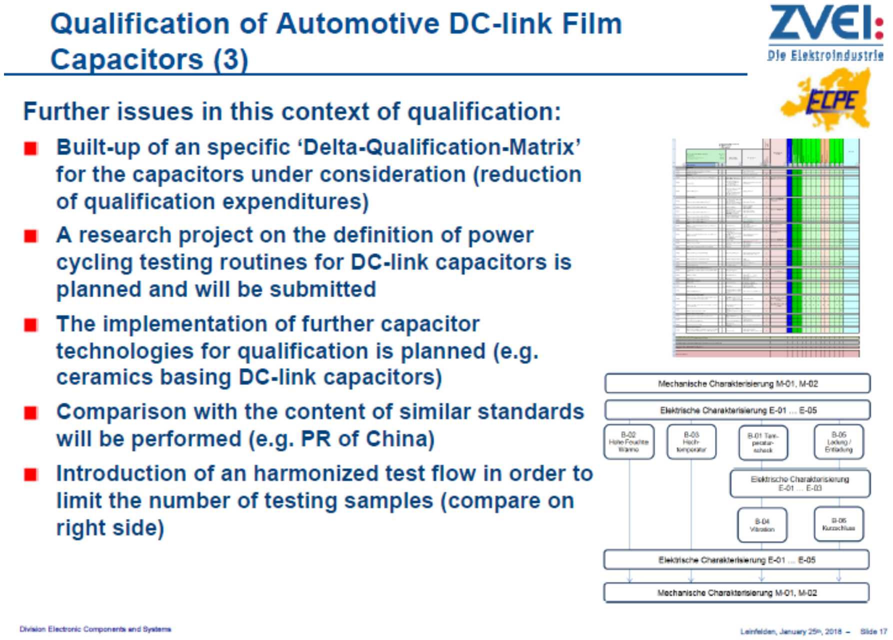


Fig. 11 Test definitions, test plan and qualification matrix for DC-ling Film Capacitors. 6 large Cs are needed for each of 4 test rows only.

O. Schilling (Infineon) explained HALT testing for industrial moduled to improve its robustness.

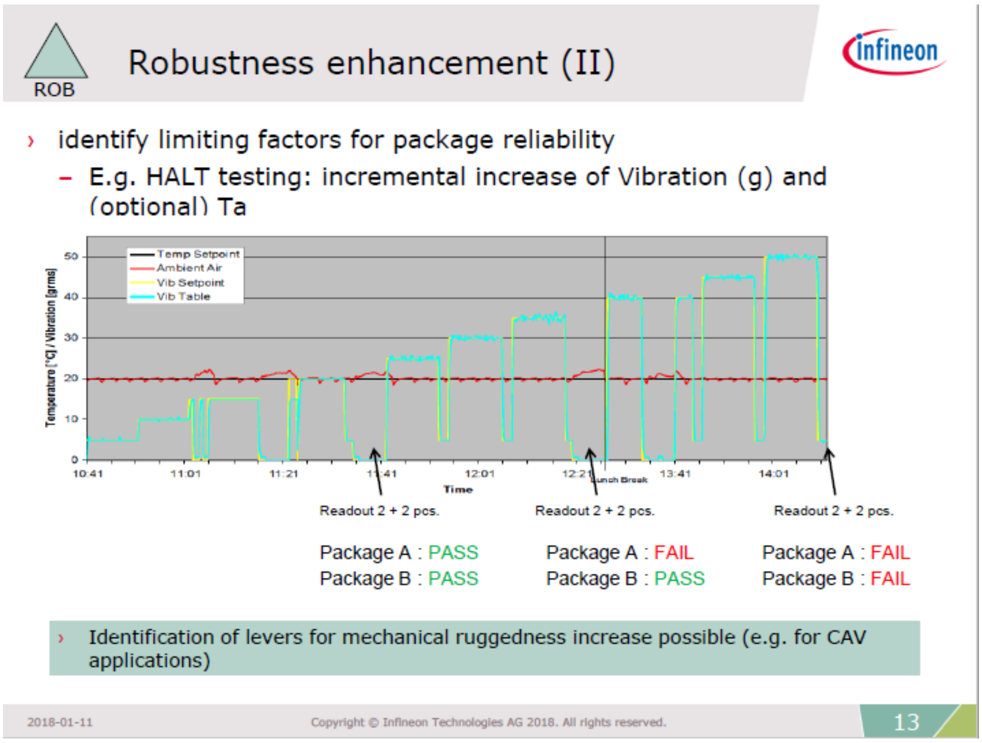
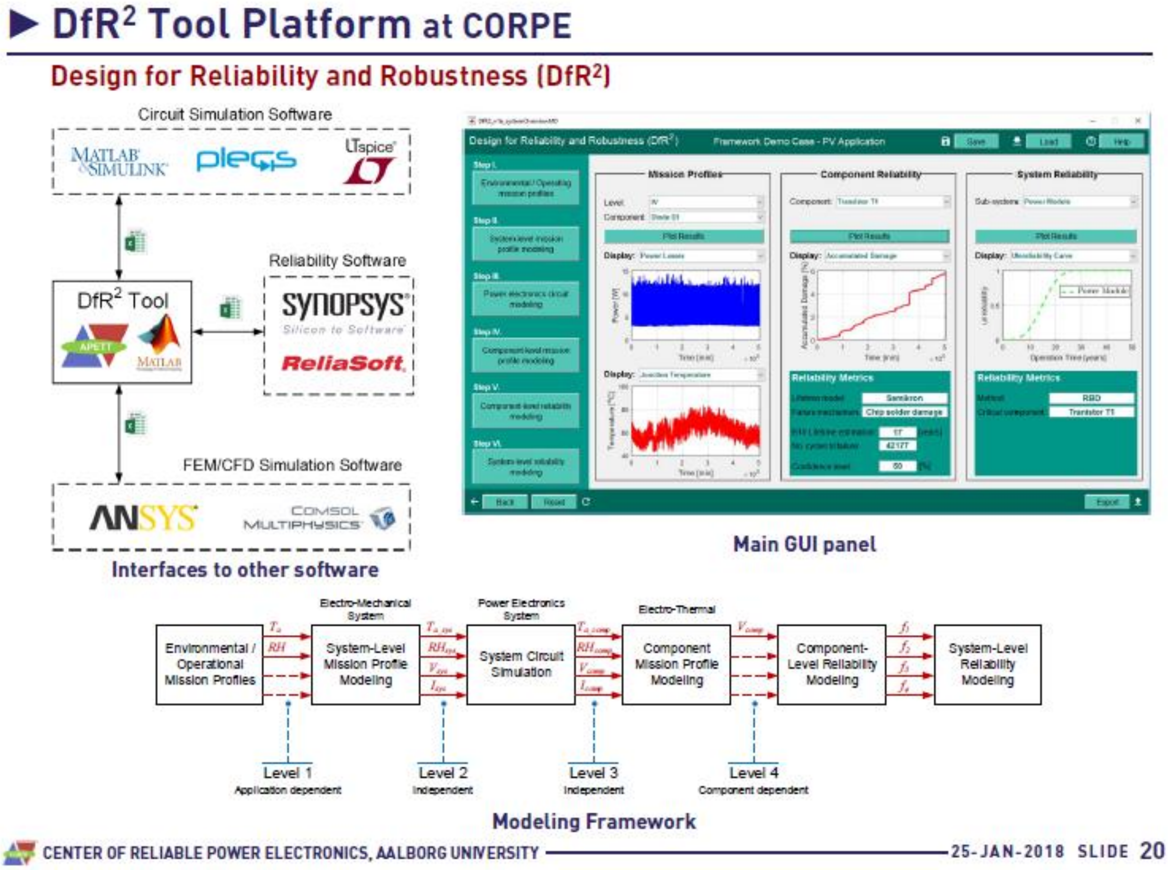


Fig. 12 Result of HALT tests (highly accelerated life test) disclosing "pass"- and "fail" situations.

H. Wang (CORPE, Univ Aalborg) talked about "Mission Profile Based System-Level Reliability Analysis of Power Electronic Converters. In the Fig. the CAD tools used are shown.



Session 4: End-of-Life Testing and Physics of Failure PoF

10:30 **Monitoring PC and TC Test** Gerard Coquery, VEDECOM (F)
10:50 **HALT and HAST Tests** Stefan Schmitt, Semikron (D)
11:10 **Simulation Based Derivation of Humidity Load Collectives** Daniel Koenig, Robert Bosch (D)
11:30 **Analytics for PoF** Matthias Petzold, Fraunhofer CAM (D)
12:10 **Ensuring the Reliability of Power Electronic Devices with Regard to Terrestrial Cosmic Radiation** Gerald Sölkner, Infineon Technologies (D)

In this session G. Coquery (VEDECOM) presented equipment which is able to monito PC- and TC- tests.
S. Schmitt (Semikron) showed how HALT- and HAST- tests can be used for development and qualifification.
D. Koenig (Bosch) discussed the impact of humidity. He concluded:

- Humidity transfer from ambient climate through mounting location into electrical control units and components can be efficiently modeled
- Mission profile and engine type have significant influence on humidity load collectives

- Foundations for model based optimizations of product robustness in respect to humidity induced failure modes established

M. Petzold (Fraunhofer IMWS) gave an overview on advanced analytical methods and tools. His summary and conclusions are:

- Illustrative examples have been given demonstrating the need for robustness validation-oriented approaches (see slides 19,20).
- RV-oriented approaches and the complexity of defect mechanisms require extended cooperation along the complete supply chain.
- RV can benefit from precompetitive research on physics of failure concepts prior to reliability investigation of products as demonstrated by three different examples from industrial use cases.
- RV-oriented approaches can also benefit from empirical experience of external failure analysis experts to establish failure catalogues with root cause correlation.
- It would be helpful to put these concepts and needs into more public focus as a significant research task to secure the market potential of innovation instead of considering it as a bothersome industrial add-on.

He also presented some ideas on:

What can we do?

- RV concepts with EOL testing and failure analysis to get information on priority risks and reliability margins

  → Increased efforts, timeline in reliability testing?
- Early research activities for basic understanding of defect risks together with introduction of new technologies
- Development of Physics of Failure concepts for critical defect mechanisms including predictive modelling as IP blocks for following reliability investigations

  → Precompetitive research in industry consortia and funded projects on PoF!
- Can not consider full complexity of processes and use conditions

  → Failure catalogues and expanded FMEA risk analysis
- Supporting conditions:

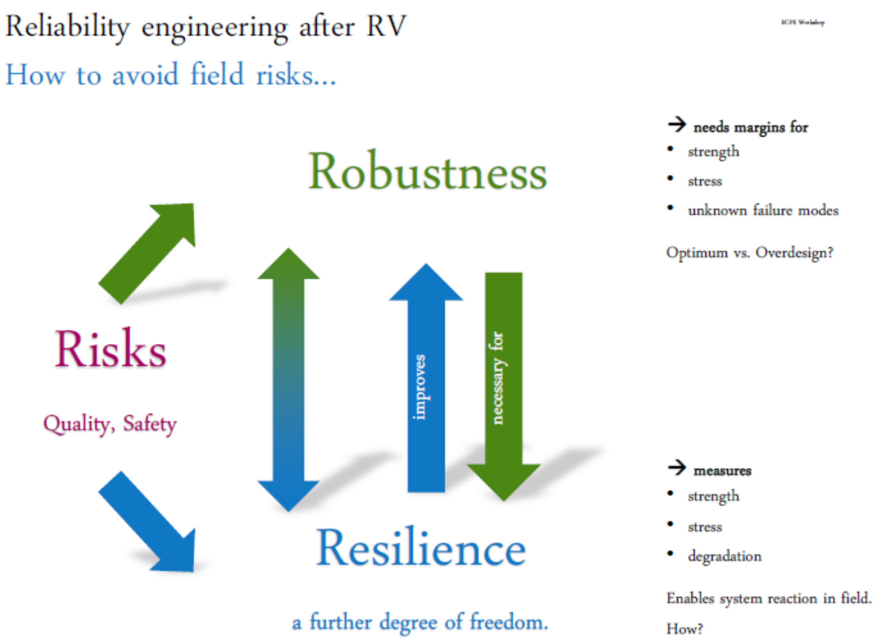
  → Cooperation along industrial supply chain from IC level to OEM

  → Benefitting from broader experience and instrumentation availability of external specialized failure analysis experts

Session 5: What about the Future?

13:40 **Resilience - Reliability Engineering after RV** Franz Dietz, Robert Bosch (D)
14:00 **Degradation - Self Correcting Systems** Andreas Preussger, Preussger Consulting (D)
14:20 **What about Closing the Loop between Target Setting, Design and Field Failures** Peter Rimmen, Danfoss (DK)

F. Dietz (Bosch) discussed what could be done after implementing the RV process- he named it **"resilience".**



He proposed the following, how to enable system reaction in the field:

Reliability engineering after RV

Chances and conflicting topics

Resilience gives the chance...

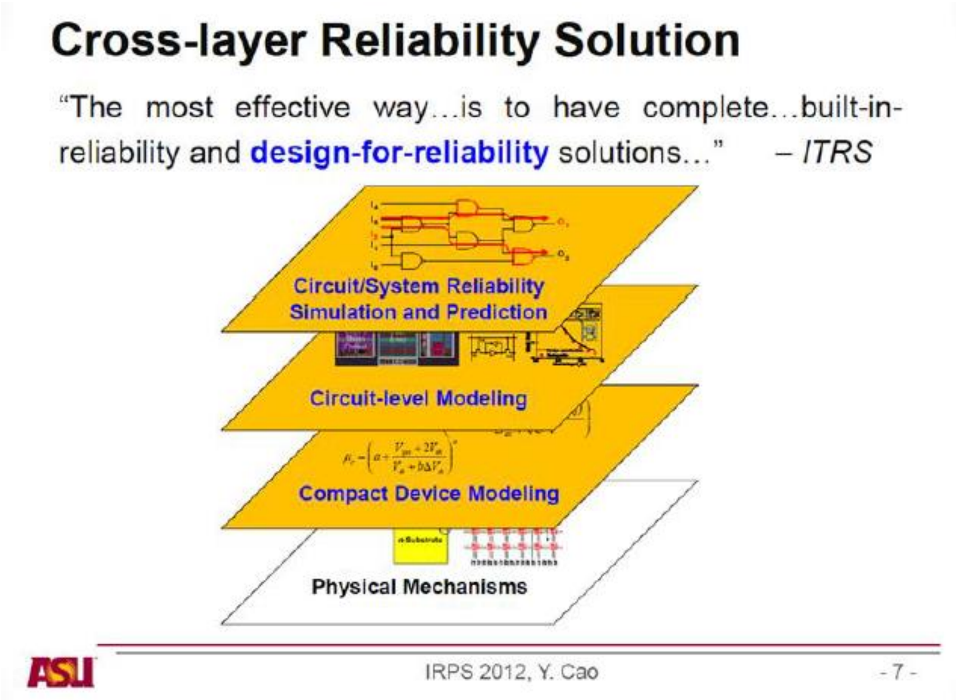
- to use "state of art" electronics in automotive
  - by perfectly understanding the **mission profile** and its relation to degradation
  - by individually triggering **system reactions** or preventive maintenance, to keep the system functional
- to **identify technical root causes** and unpredicted failure modes by **big data analysis**.
- to protect and **safeguard non-resilient components** by **condition monitoring** and correlations to the integrated detectors.

But we must be aware of:

- Resilience can help to optimize but **cannot replace Robustness**!
- Integrated resilient modes: must be **qualified** and considered through the system hierarchy!
- **Data security**: we must make sure the system is not compromised!
- Deep understanding of physics of failure and **system knowledge** is necessary to use the resilience data correctly.

Cooperation through the complete value chain will be the key to success!

A. Preussger mentioned the Cross-layer solution and gave an examples for "Degradation - Self Correcting Systems".

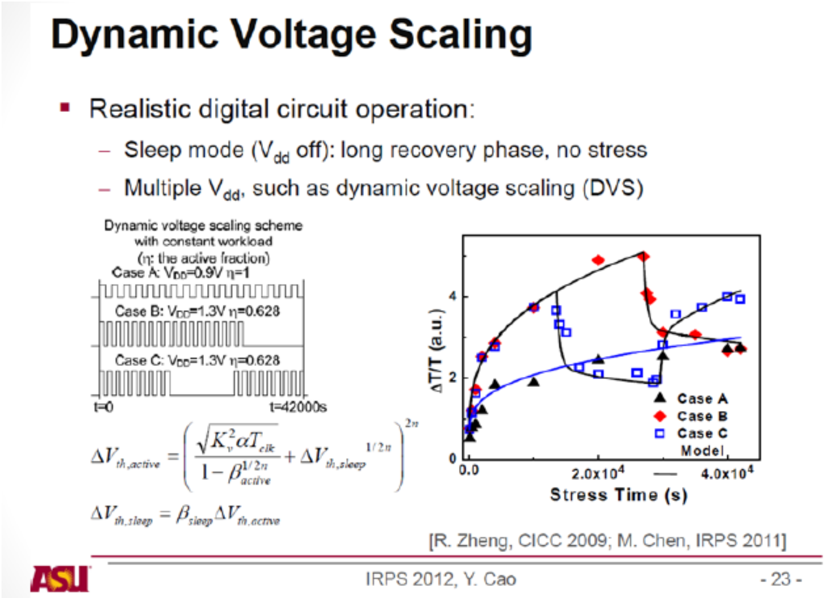


He is in favour of health monitoring strategies:

- Degradation / health monitoring driven control strategies
  - Frequency scaling
  - Voltage scaling
  - Back bias scaling
- Replica circuits
  - Activated with every cycle
  - Must represent most critical path
  - Tunable to calibrate sensitivity wrt critical path
  - Measure reliability e.g. delay

- Assessment
  - Pro: no over engineering, response to the individual reliability status of the IC, re-execution of computation in case of error
  - Con: additional circuit/chip area, false positive/negative to be kept under control

For the case of dynamic voltage scaling an example is shown where due to a higher frequency and breaks the temperature stress can be reduced.



In summary:

Reliability knowledge generated by applying Robustness Validation during Product Qualification could be used for more than just demonstrating that the correct safety margin has been designed in.

P. Rimmen (Danfoss) finally talked about implementing knowledge of field failures into the design process.

The Future based on the Physics and Statistics.

Weibull & MCF or M(t)

Design phase: Weibull (proactive)

Reliability target setting (budgeting)

- 0-times failure (transportation and installation)
- Early failures (supplier and production)
- Random failures (RIF) Robustness
- Wear out failures
  - "How to measure lifetime RV...."
  - Follow up during the design phase

Field failure analysis: MCF or M(t) (reactive)

- Statistics (read the MCF and compare with target) and Early Warning
- Physics of Failure

The Future wish from Danfoss to the Universities are:

Educated **Design engineers**, who master:

- **Physics of Failures**
- **Statistics**: Six Sigma philosophy, at Green Belt level,
  - DMAIC (Define, Measure, Analyse, Improve and Control) or IDOV (Identify, Design, Optimize and Verify)
  - DoE, Gauge R&R, C_{pk}, Confidence, Think Variance. Not Average and not single value.
  - S-, D- & P-FMEA on design proposals.

Educated **Reliability engineers**, who **also** master:

- **MCF and Weibull**
  - Reliability Budgets
  - Severe user concept. Understand mission profiles and field load
  - End of life specification / degradation
  - Test purpose, statistical approach, Qualitative and Quantitative test.
    - Hi/Lo temperature test, Highly Accelerates Limit Test and Calibrated Accelerated Life Test.
  - Multiple Environmental Over Stress Testing (MEOST)
- One Reliability language
  - Robustness Validation (ZVEI)
- Financial model for COPQ reliability
  - Customer and Management views.
- "Why not use:" Outdated Models and Terms based on: Bath tub, FIT, MTBF, Failure rate

Two **panel discussions** on
"Design and Technology" moderated by J. Breibach (Bosch) and
"What about the Future" moderated by W. Kanert (former Infineon) with time slots of 2h and 1h respectively allowed a very intensive discussion of the topics presented.