INDUSTRIAL SESSION EPE 2009: Key Note 2-C

Reliability of Power Electronic Systems

Eckhard Wolfgang, ECPE, Nuremberg, Germany
Kai Kriegel, Siemens CT, Munich, Germany
Wolfgang Wondrak, Daimler, Germany

Acknowledgement:
Rolf Winter/ ZVEI, Helmut Keller/ SIA International,
Siegfried Ramminger/ Siemens CT,
Olivier Tachon/ Airbus, Gerard Coquery/ INRETS,

Content

Robustness Validation

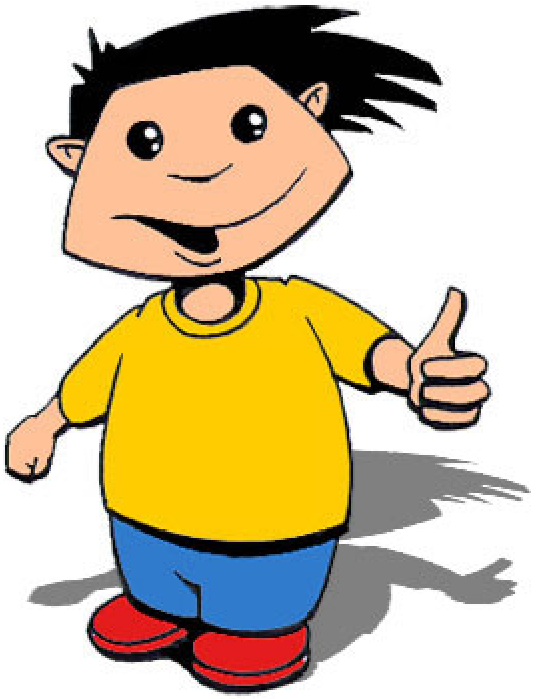
The fast paced development of Automotive Electronics requires a paradigm shift in Validation to meet reliability challenges for current and future products

Chair: Helmut Keller
Secretary: Dr. Rolf Winter

Knowledge based vs. stress based qualification

Knowledge Based Qualification	Stress Based Qualification
More reliability analysis in the run-up to and during development	Cookbook like process
Physical degradation models	Broadband approach
Failure mechanism specific tests	Unspecific tests
Fast and selective failure analysis	Complex failure analysis
FIT FOR APPLICATION	FIT FOR STANDARD

Robustness Validation Handbook



See: http: // www.ZVEI.org/RobustnessValidation

also for Knowledge Data Base and Template

Workgroup Robustness Validation (ECU level)
Participating companies and organization

+
Automotive Lighting
Agilent
AB Mikroelektronik
Analog Devices
Cherry
General Motors
Ford Motor Company
HKR climatec
On Semiconductor
Robert Seuffer

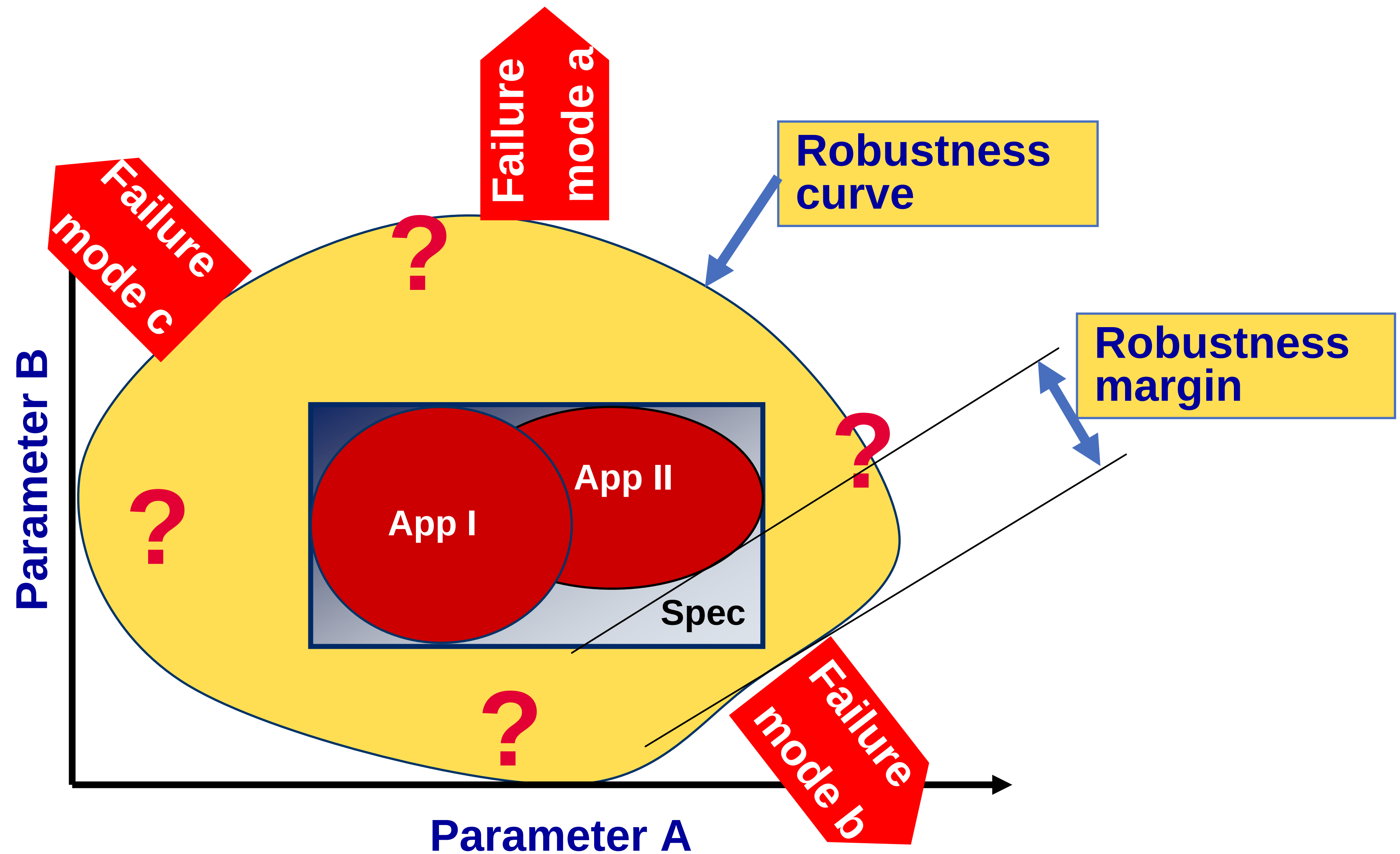
Robustness Validation

Robustness Validation is a process to demonstrate that a product performs its intended function(s) with sufficient **robustness margin** under a defined **mission profile** for ist specified lifetime.

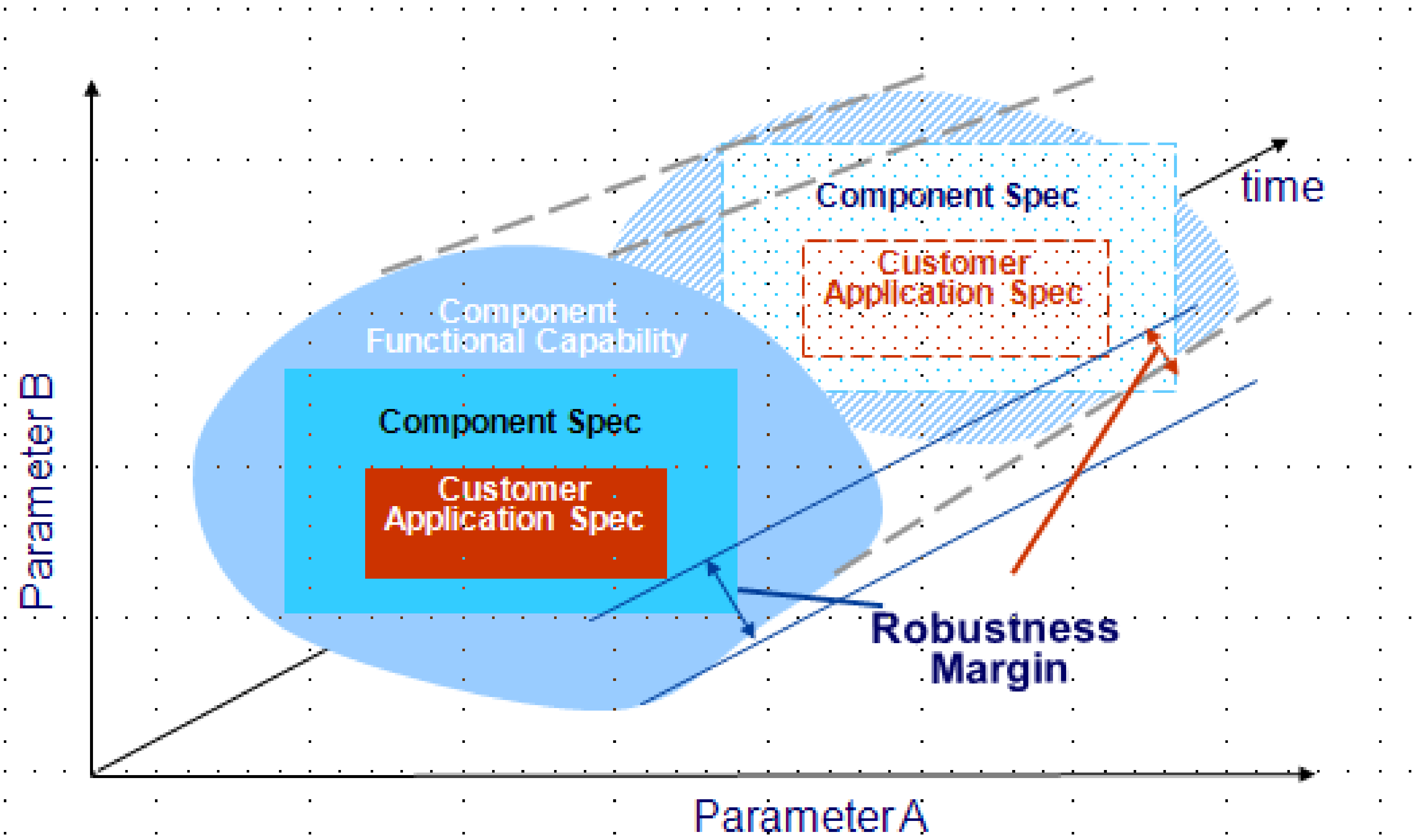
It should be used to communicate, analyze, design, simulate, produce and to test an EEM in such a manner, that the influence of noise (or an unforseen event) on an EEM is minimized.

EEM   Electrical/ electronic module

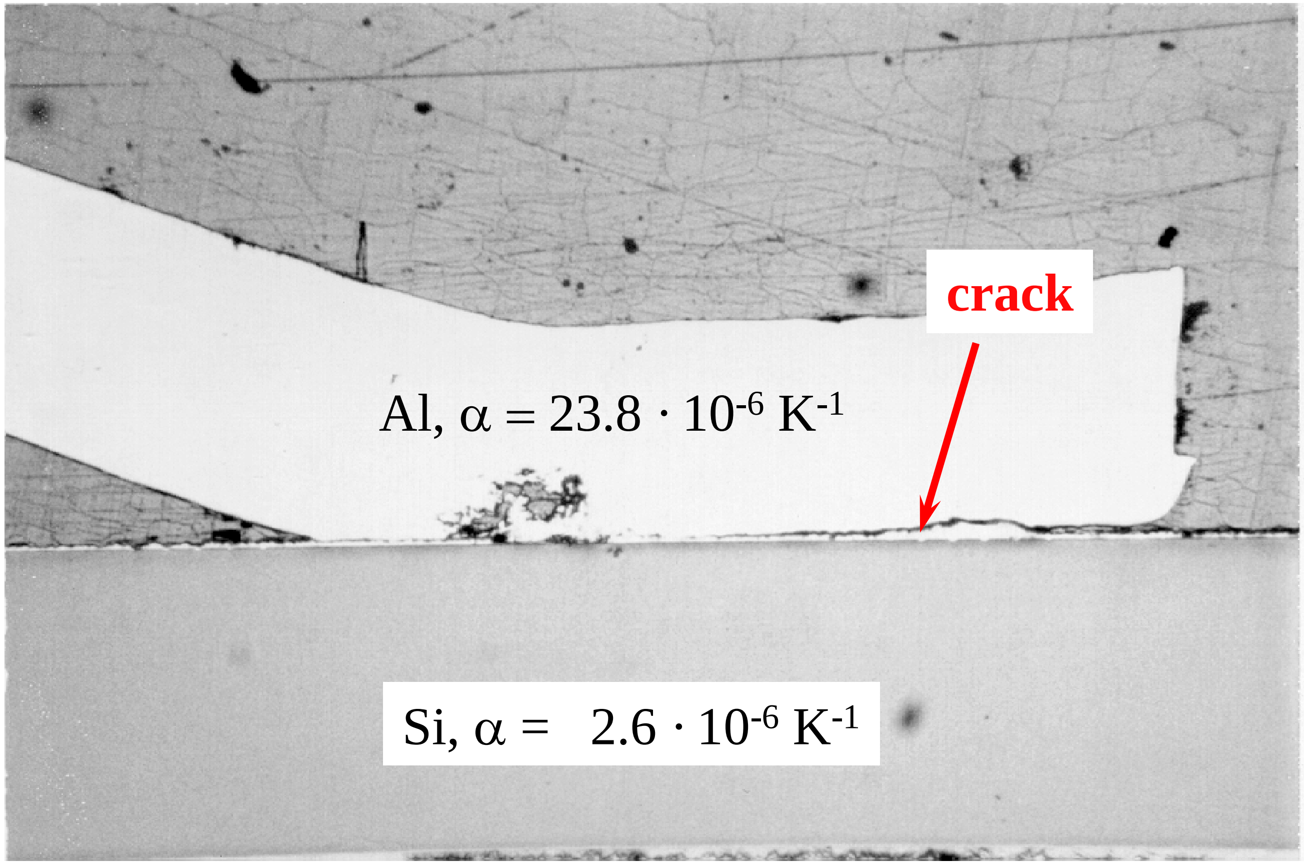
Robustness Margin



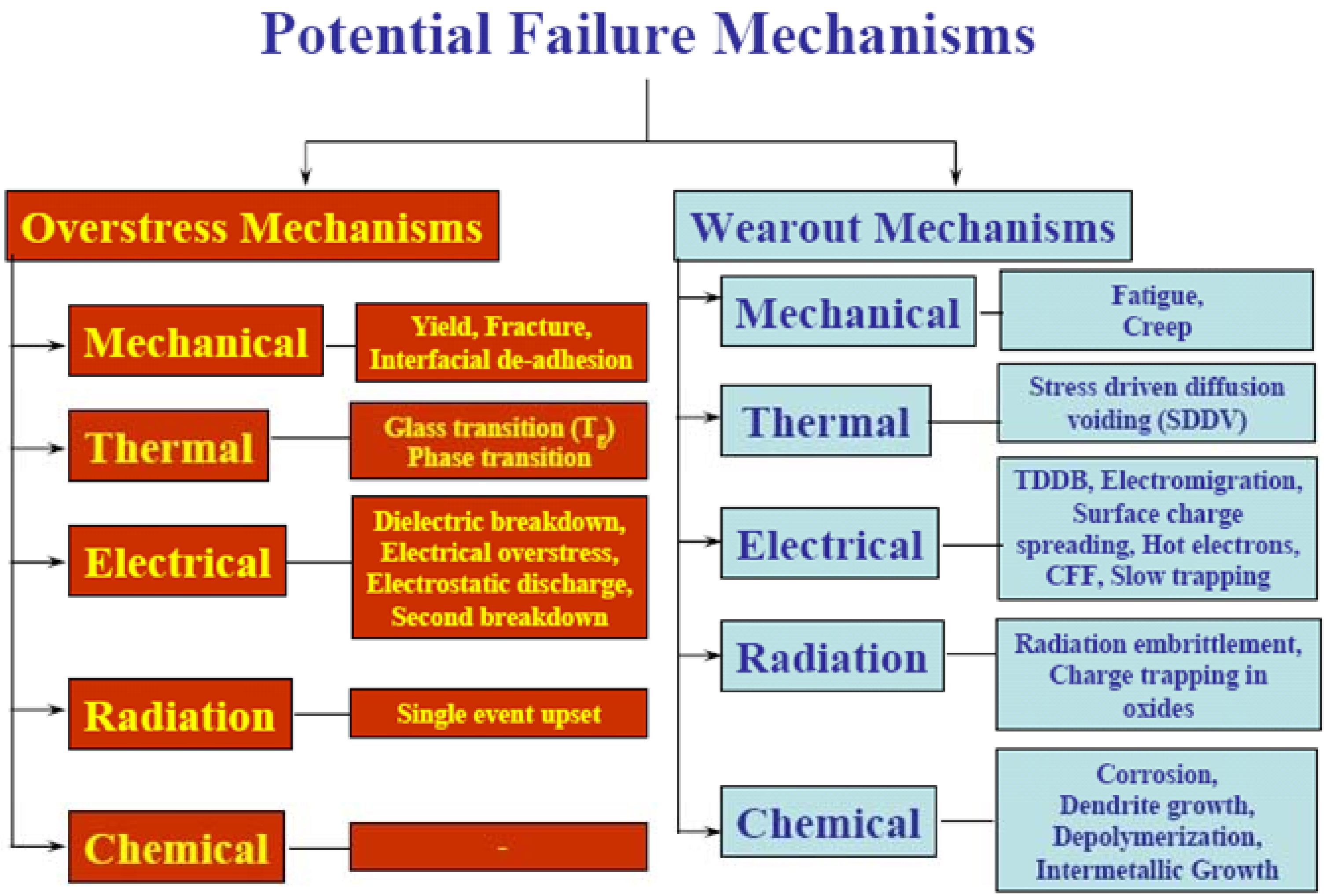
Robustness Margin



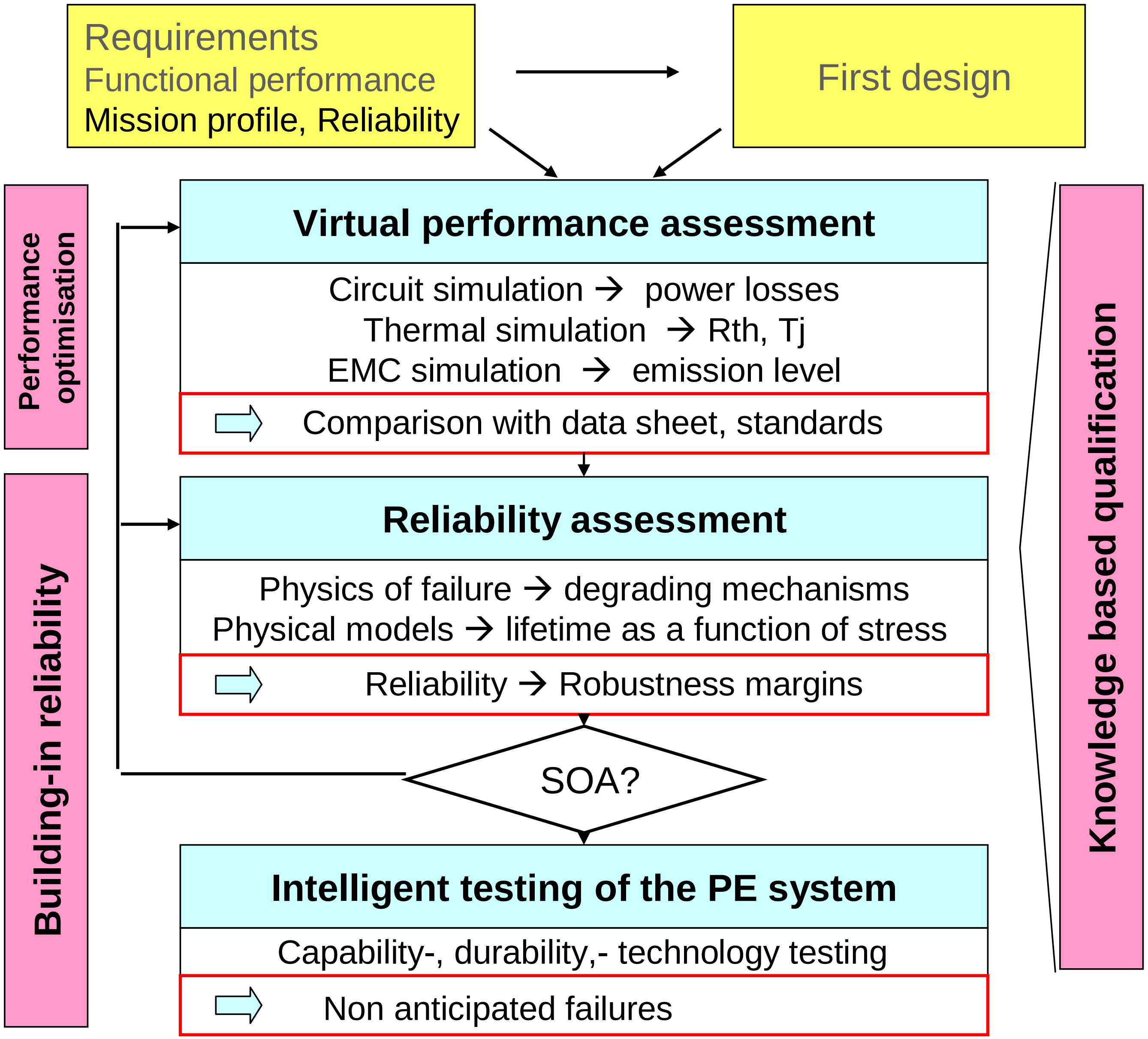
Failure Mechanism: Al- Wire Bond Lift-off



Physics of Failure Approach



Securing Reliability in the Design Phase



Mission Profile

The ***Mission Profile*** is a representation of all relevant conditions an electric/lectronic module will be exposed to in all of its intended applications throughout ist entire life cycle.

It is therefore important that the Mission Profile for each individual electrical/electronic module is developed and communicated to the engineers designing the module as soon as possible.

With a good description of the Mission Profile, engineers can begin to estimate reliability and quality levels and start to work toward achieving „zero defects“ and robust design at all levels of the supply chain.

Mission Profile for a Hybrid Electric Vehicle Delivery Van:
„door to door delivery“ measured by a GPS system

Figure 4: The "HyTrans" hybrid van

4.1 Door to Door mission profile

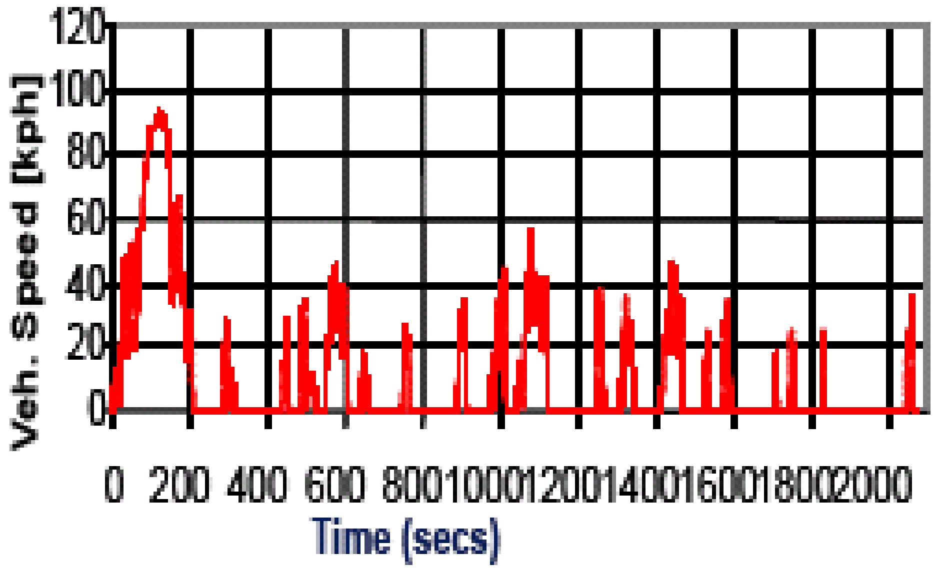


Figure 5: Proposed "door to door delivery" cycle.

Automotive Power Electronics Conference, Paris, June 21,22,2006

Mission Profiles for Hybrid Automotive Applications and their Application to Battery Testing

Dr Peter Miller

Ricardo Plc, Cambridge Technical Centre, Milton Road, Cambridge, UK.

ARTEMIS Drive Cycle (EU FW 5)

- There are 4 ARTEMIS "Basics" Cycles:

	Duration	Average Speed	Max Speed
Jam	933s	8km/h	33km/h
Urban	918s	16km/h	57km/h
Road	982s	60km/h	110km/h
Highway	1064s	97km/h	150km/h

- From these 4 cycles, we have defined a "life" cycle made of:
  - 4 jam
  - 3 Urban
  - 2 Road
  - 1 Highway

	Duration	Average Speed	Max Speed
Life	9517s (158mn)	31km/h	150km/h

- The vehicle life time is to targeted 360 000km that is 11500 "life" cycles

Functional Loads in Vehicle

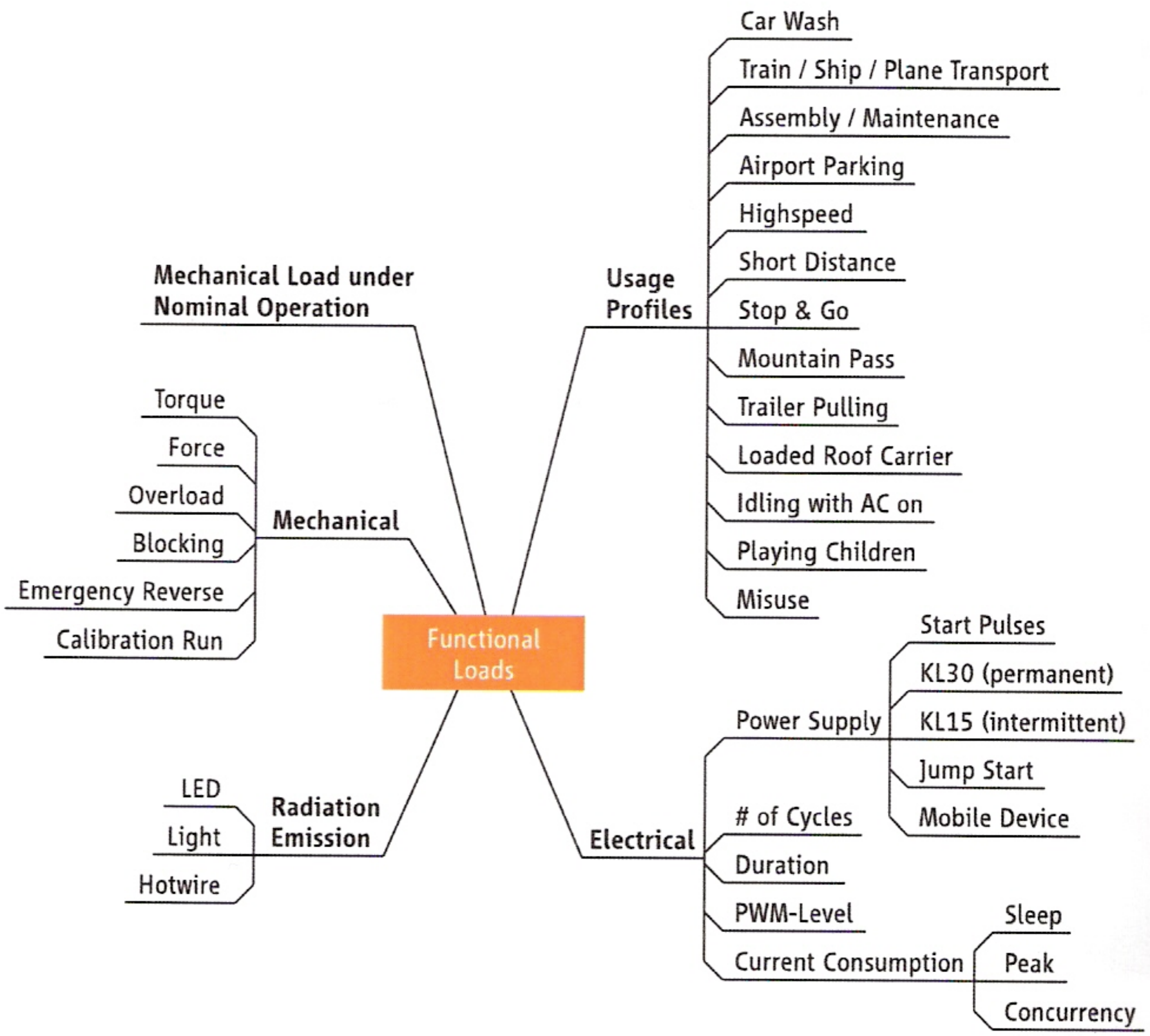


Figure 6.5 Tree Analysis of Functional Loads

Environmental Loads in Vehicle

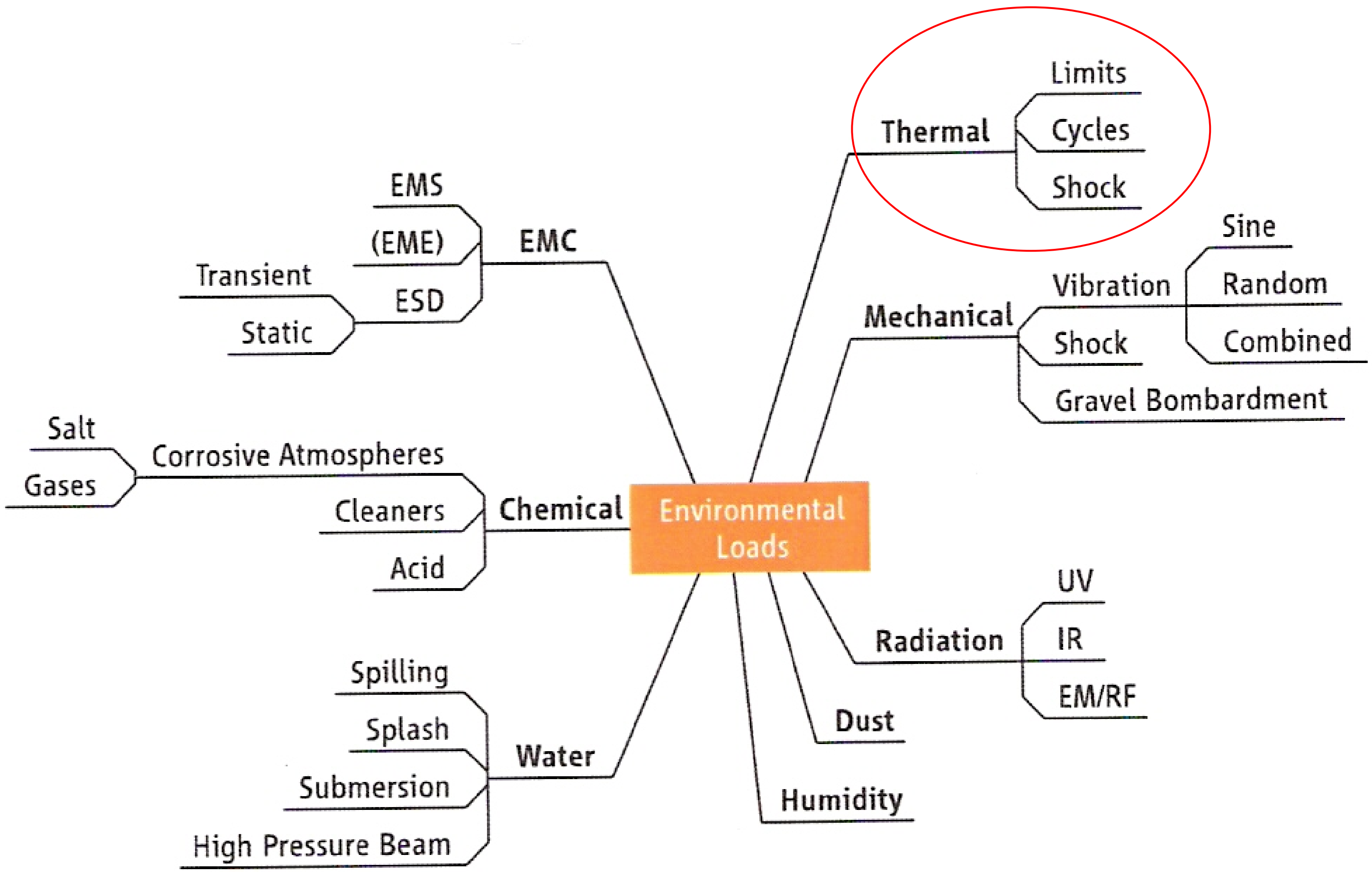


Figure 6.4 Tree Analysis of Environmental Loads

Mission Profile for Engine Mounted Control

Operation Time

		Unit
Lifetime	15	years
Operation time (in15 years)	10.000	hours
Mileage	300.000	km
Temperature cycles / year	700	
Temperature cycles / total	10500	

Ambient temperature (air)

	Temp. 1	**Temp. 2**	**Temp. 3**	**Temp. 4**
Duration %	6%	20%	65%	9%
Temperature	-40° C	+23° C	+95° C	+150° C

Coolant temperature

up to 105 °C	95%
up to 120 °C	5%
max. 128 °C	

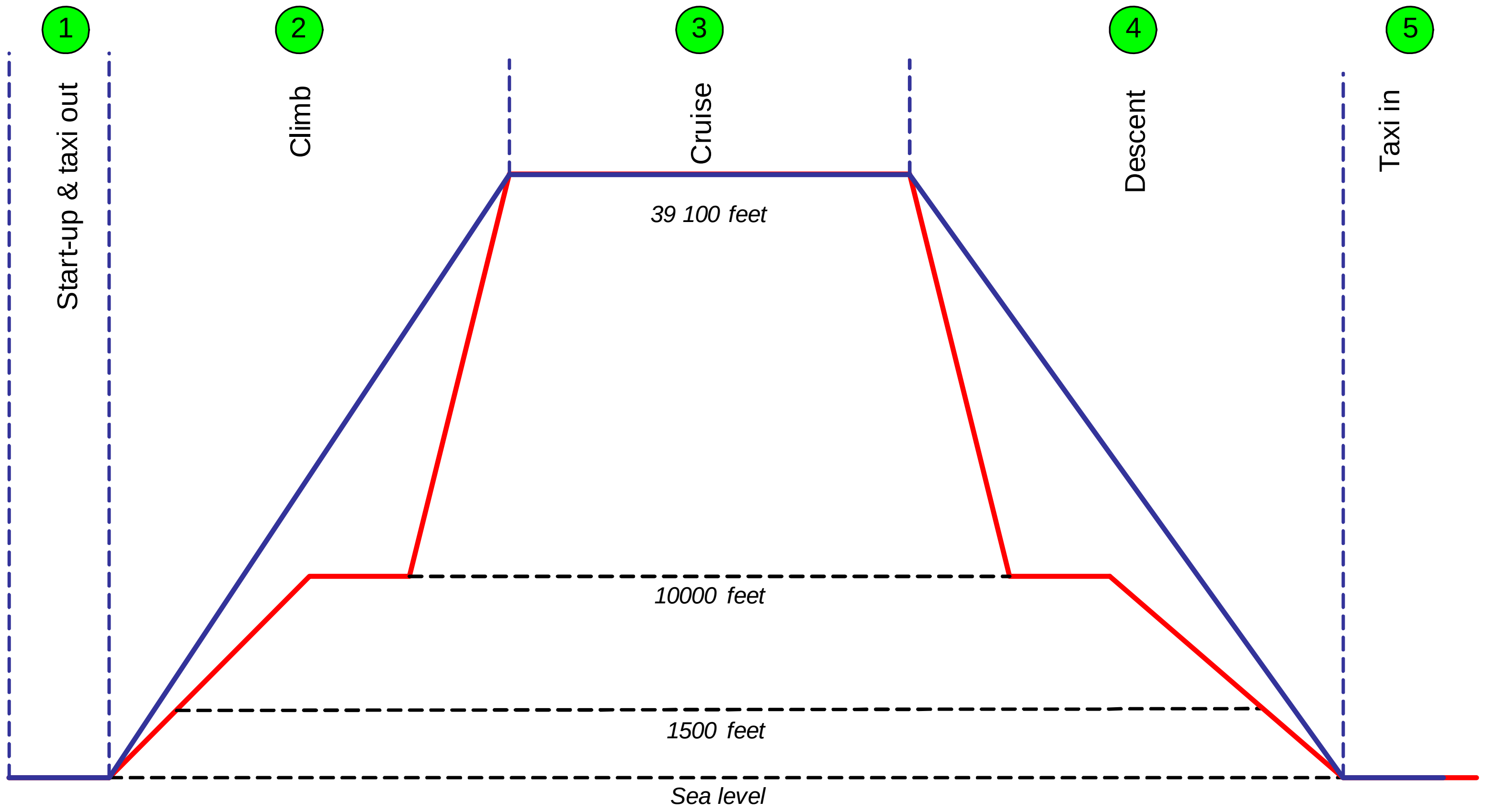
up to 80 °C	95%
up to 85 °C	5%
max. 85 °C	

Vibration

	Min	Typ	Max	Unit
acceleration	50	**160**	280	m/ sec^2
	Frequency range: 1 – 2000 Hz			

Introduction of low temperature water cooling mandatory

A320 Mission Profile

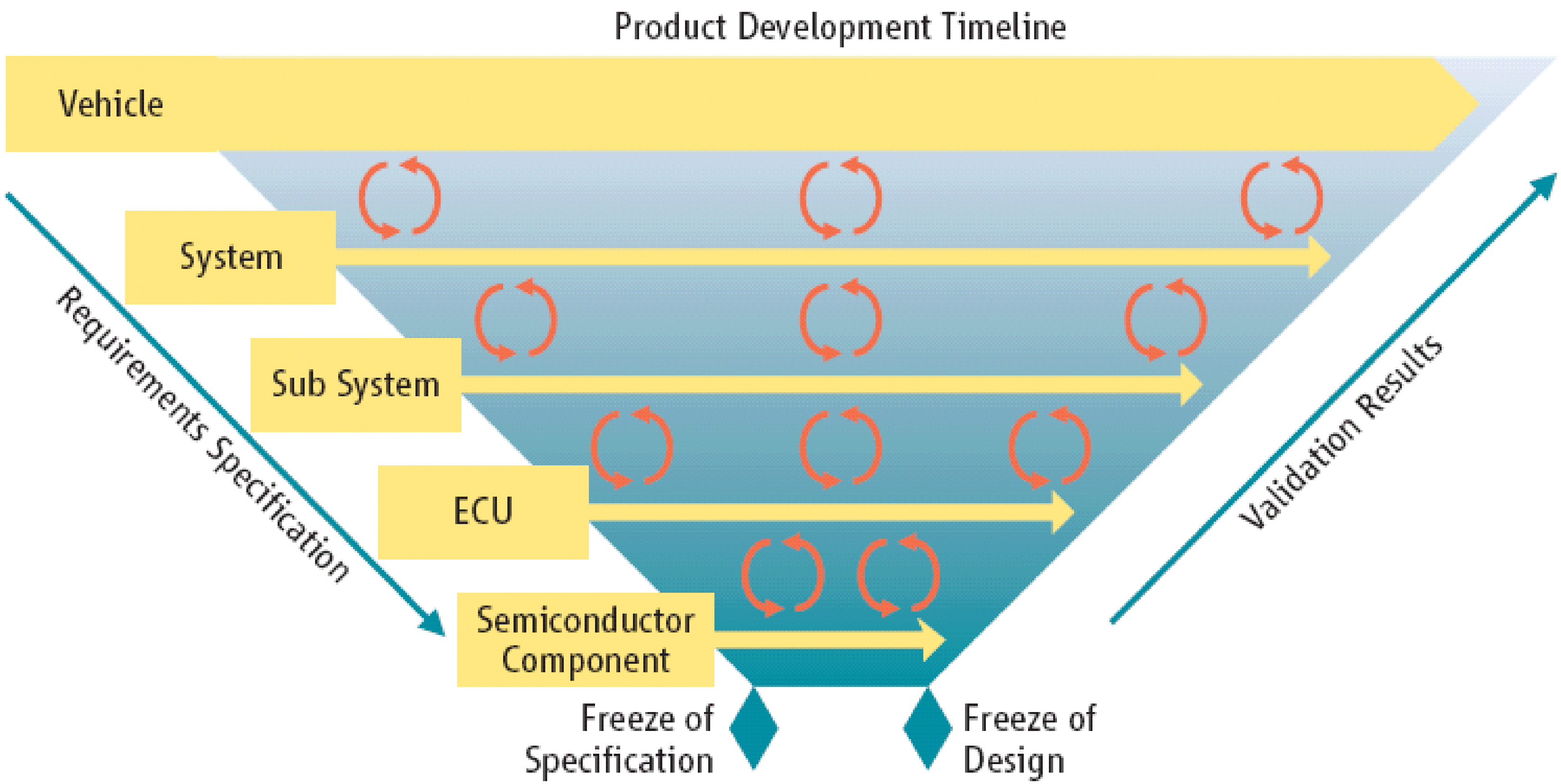


Reference mission

Simplified mission

Source Airbus

Mission Profile: Conditions of use

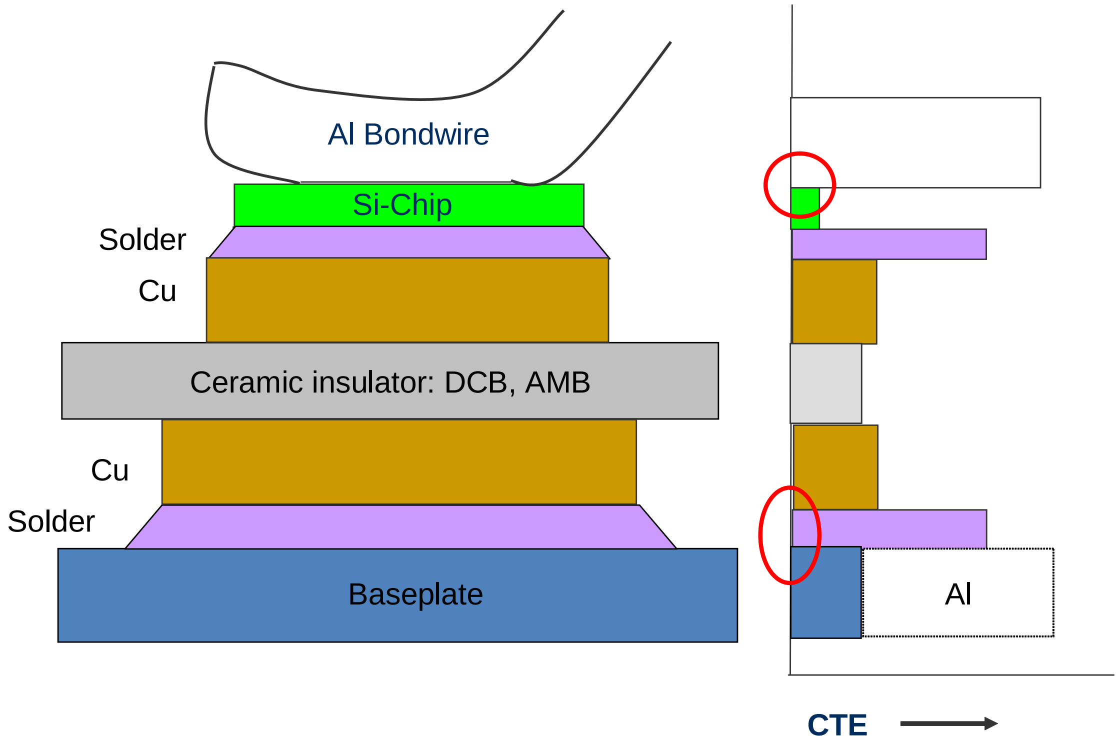


Source: Robustness Validation Handbook

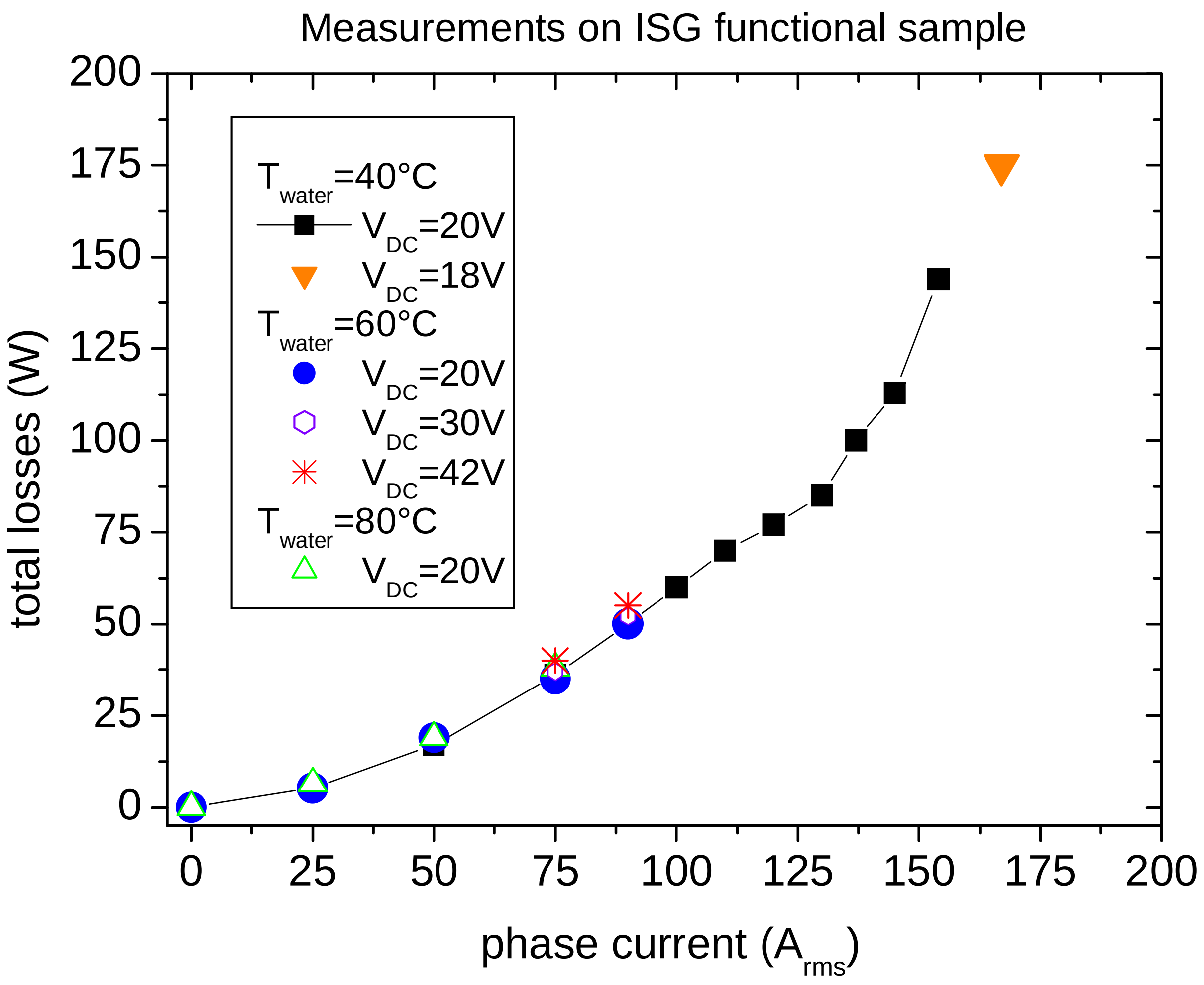
Translation of Mission Profile into Power Electronics

Given: Drive cycle = Speed vs time

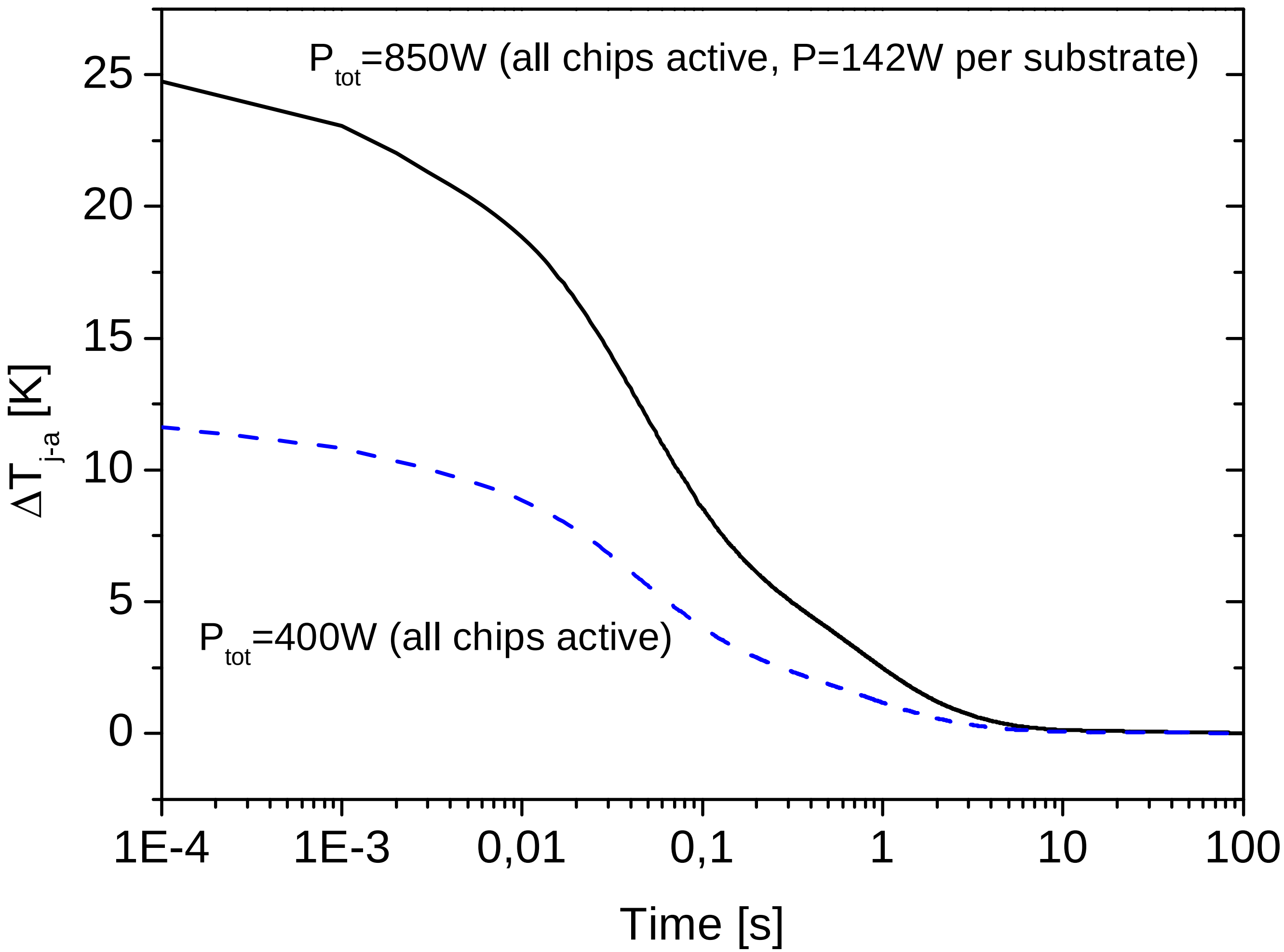
Objective: Damage caused in the power module by the number and swing of temperature cycles



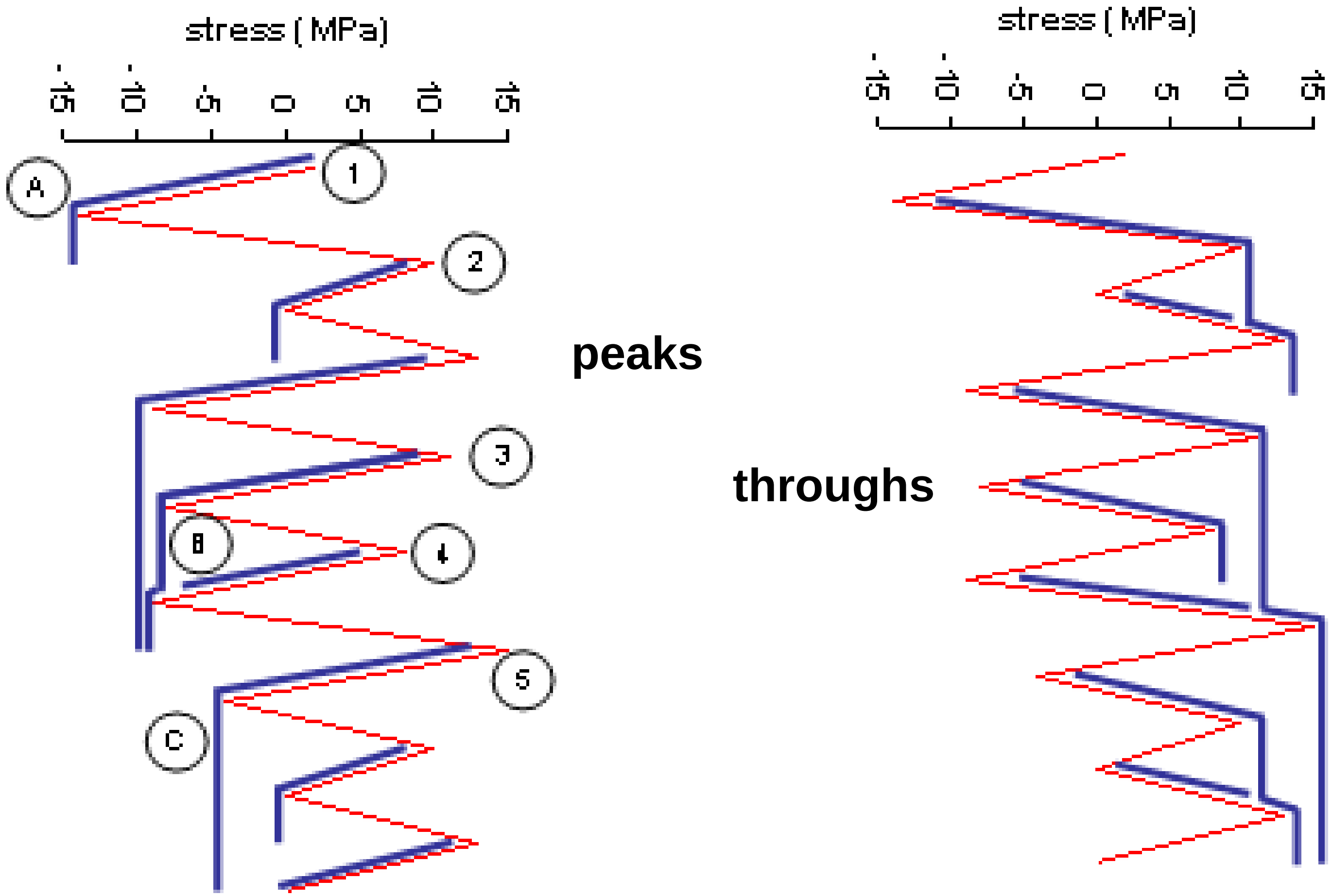
MOSFET Power Losses at Different Cooling Temperatures and Voltages



MOSFET Junction Temperatures Measured on a Multi-Chip Test Structure



Rain-flow Counting Method

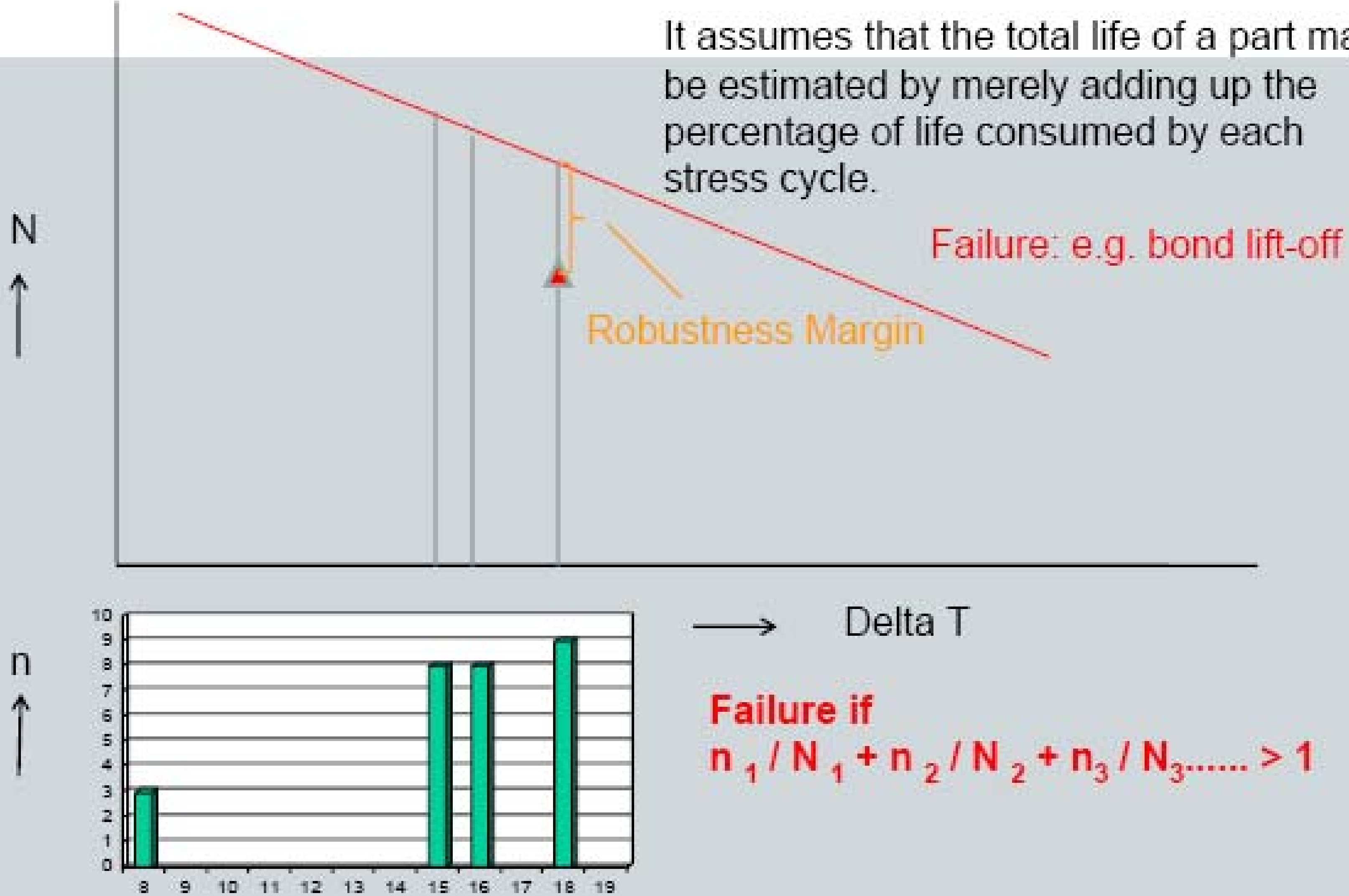


The **rain-flow-counting method**is used to reduce a spectrum of varying temperatures into a set of simple temperature reversals.

Palmgren – Miner Rule

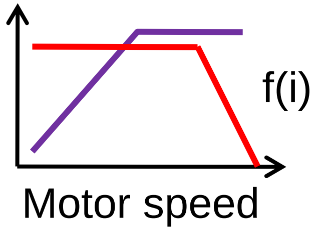
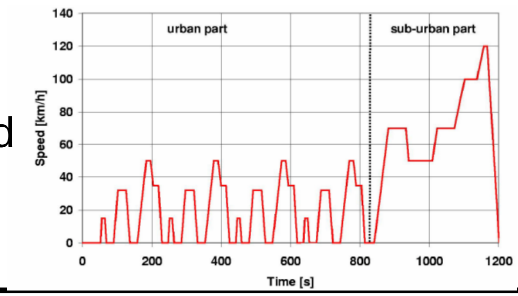
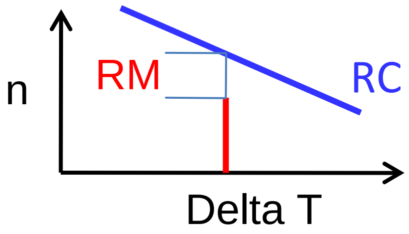
SIEMENS

It assumes that the total life of a part may be estimated by merely adding up the percentage of life consumed by each stress cycle.

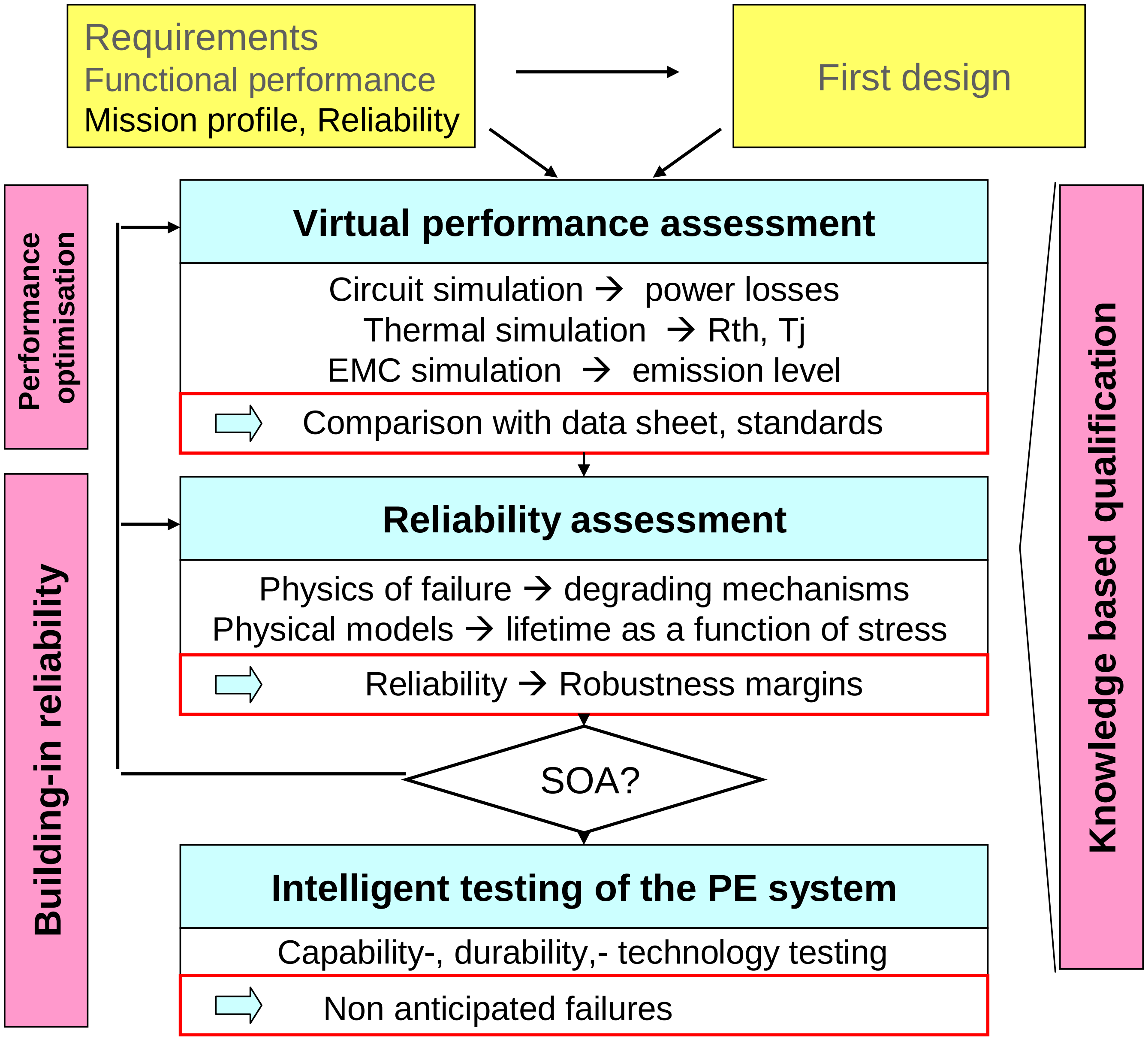


Failure if

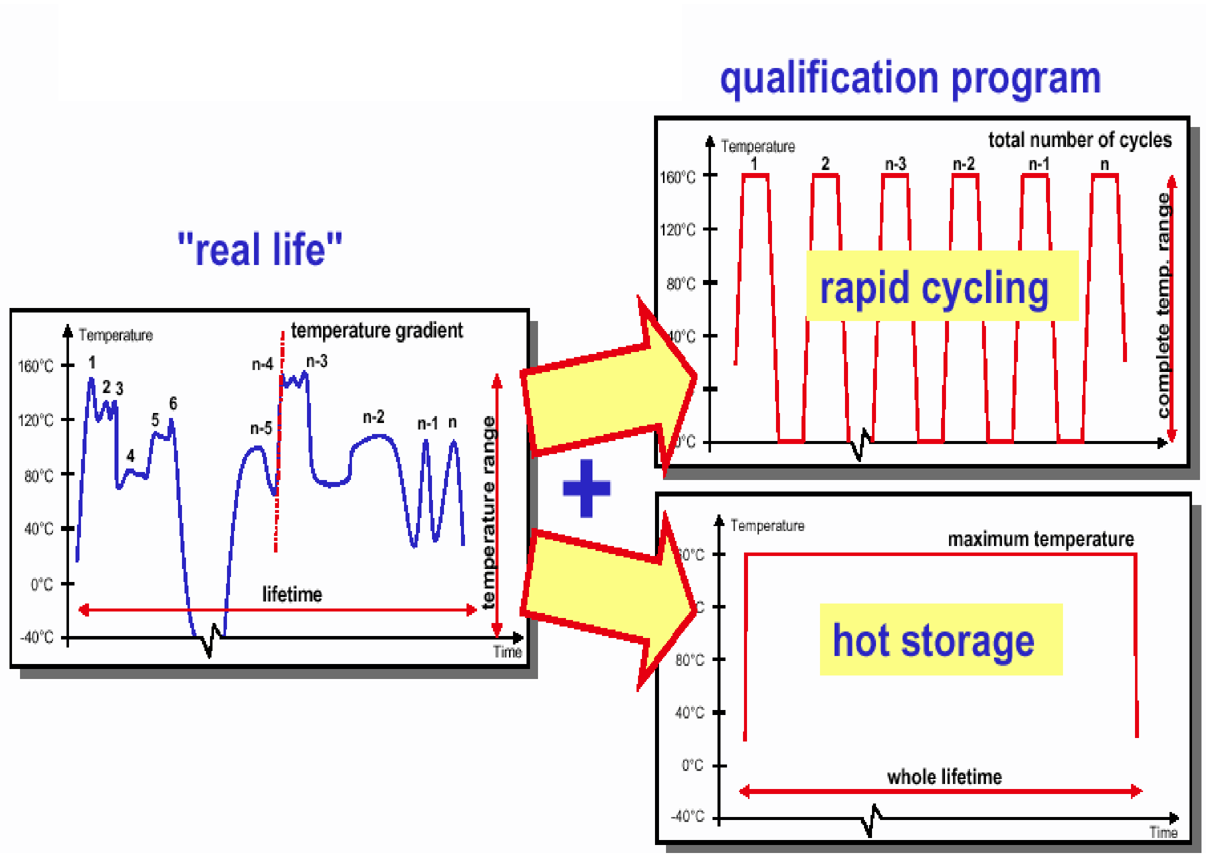
$n_1 / N_1 + n_2 / N_2 + n_3 / N_3 ...... > 1$

1	AC current needed by E-Machine	PWM index Power factor 	**TBD** E-Machine Type, spec
2	Mission Profile: NEDC	Speed  20 min	**TBD** Specific drive cycle
3	Thermal performance and load	Type of cooling Losses of power semiconductors Thermal impedance → **Histogram: Number of Delta Ts**	
4	Robustness Margin RM	Reliability curve from Manufacturer RC 	

Securing Reliability in the Design Phase



Qualification Method



Failure Modell

Coffin Manson

$N_2 / N_1 = (\Delta T_1 / \Delta T_2)^n$

$n = 1.9 \ldots 4$

Arrhenius Law

$t_2 / t_1 = \exp(E_a/kT_2 - E_a/kT_1)$

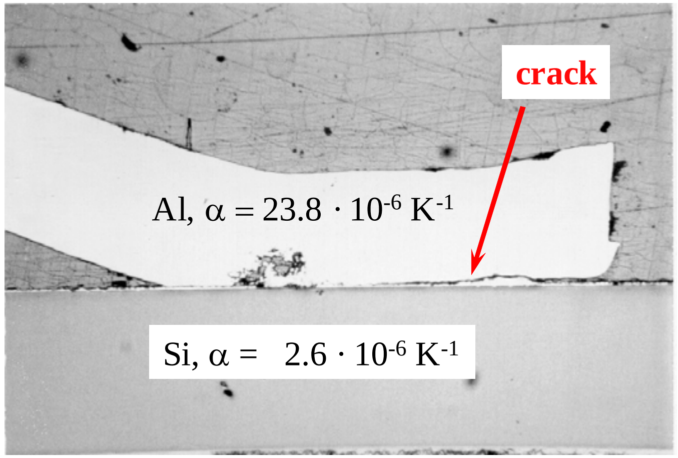
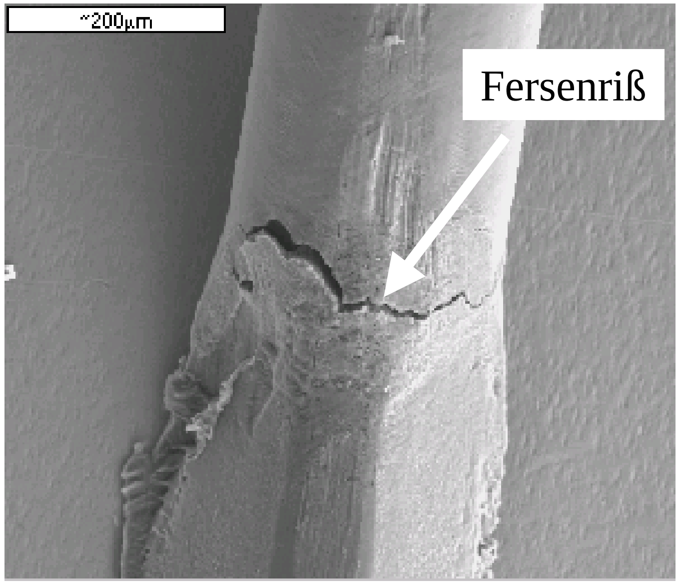
$E_a = 0.2 \ldots 1.1$ eV

Knowledge Matrix

A ***Knowledge Matrix*** is a repository (data base) for systematic failures, i.e., failures that are systemic or inherent in the product By design or technology.

The Knowledge Matrix is a collection of the lessons learned by the Organisation using the Robustness Validation process.

Failure mechanisms Thick Al Bond Wire

a. Bond Lift-off	Cross section 
b. Bond Heel-crack	

Intelligent Testing

The ***Intelligent Testing*** approach requires a change of mindset as well as strong communication throughout the complete value chain.

It defines not another “cook book” style test specification, but instead gives a general guideline on how to get comprehensive robustness information about the product.

Aim:

- Basic validation of EEM
- Identify robustness margin early in development phase

Results are used for:

- Calculation of robustness indication figure
- Production ramp up
- Control of production process (SPC etc.)
- Definition of revalidation

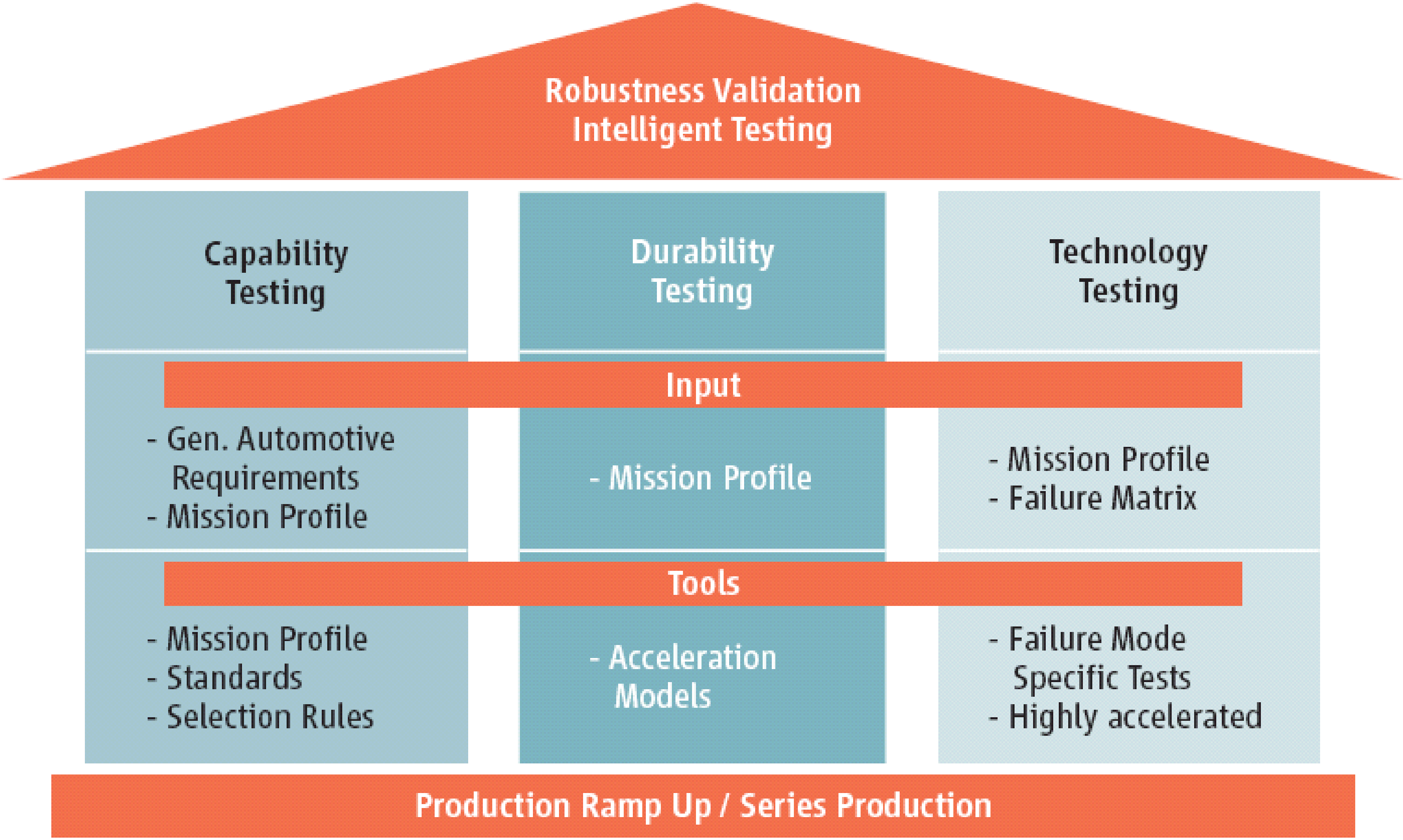
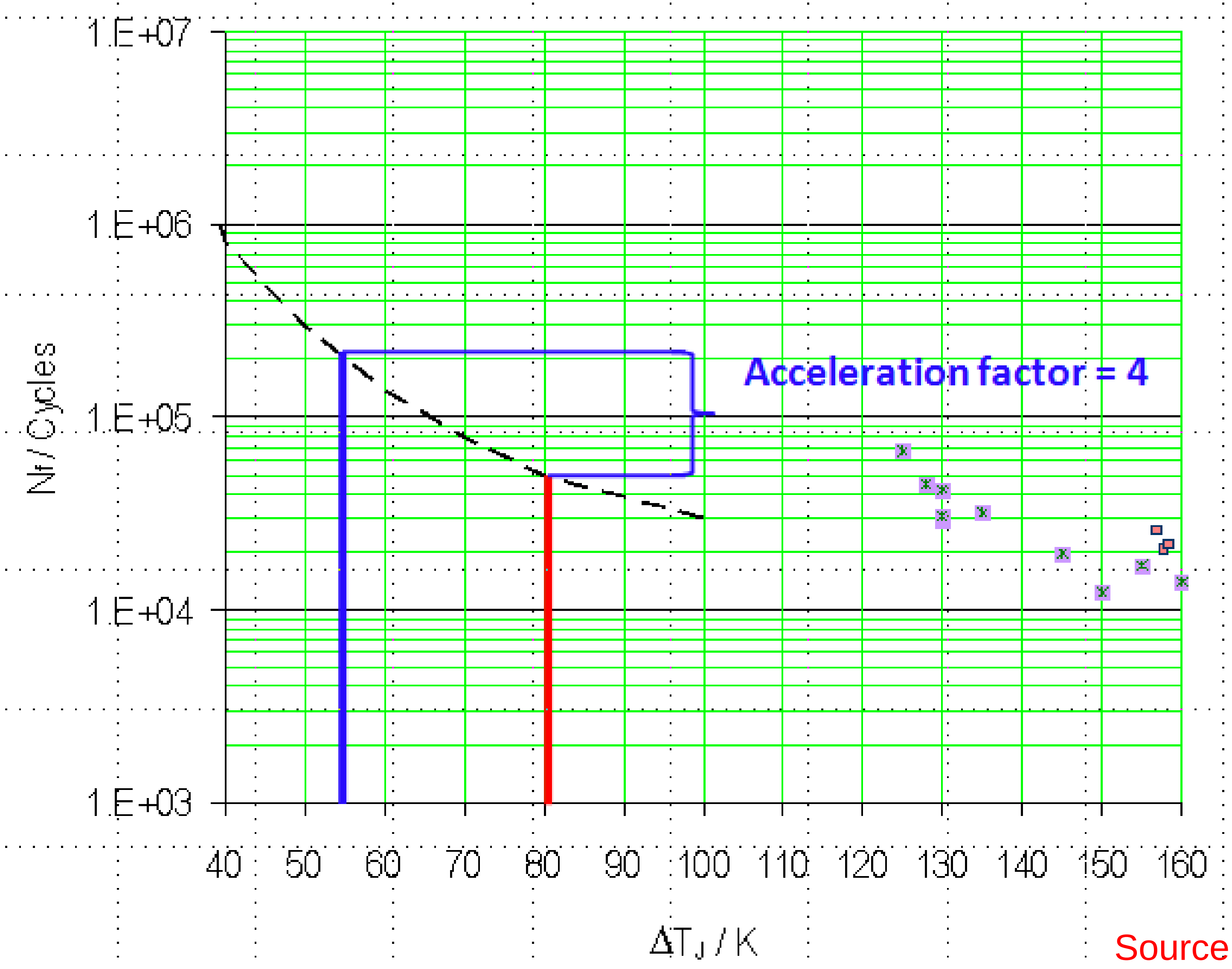


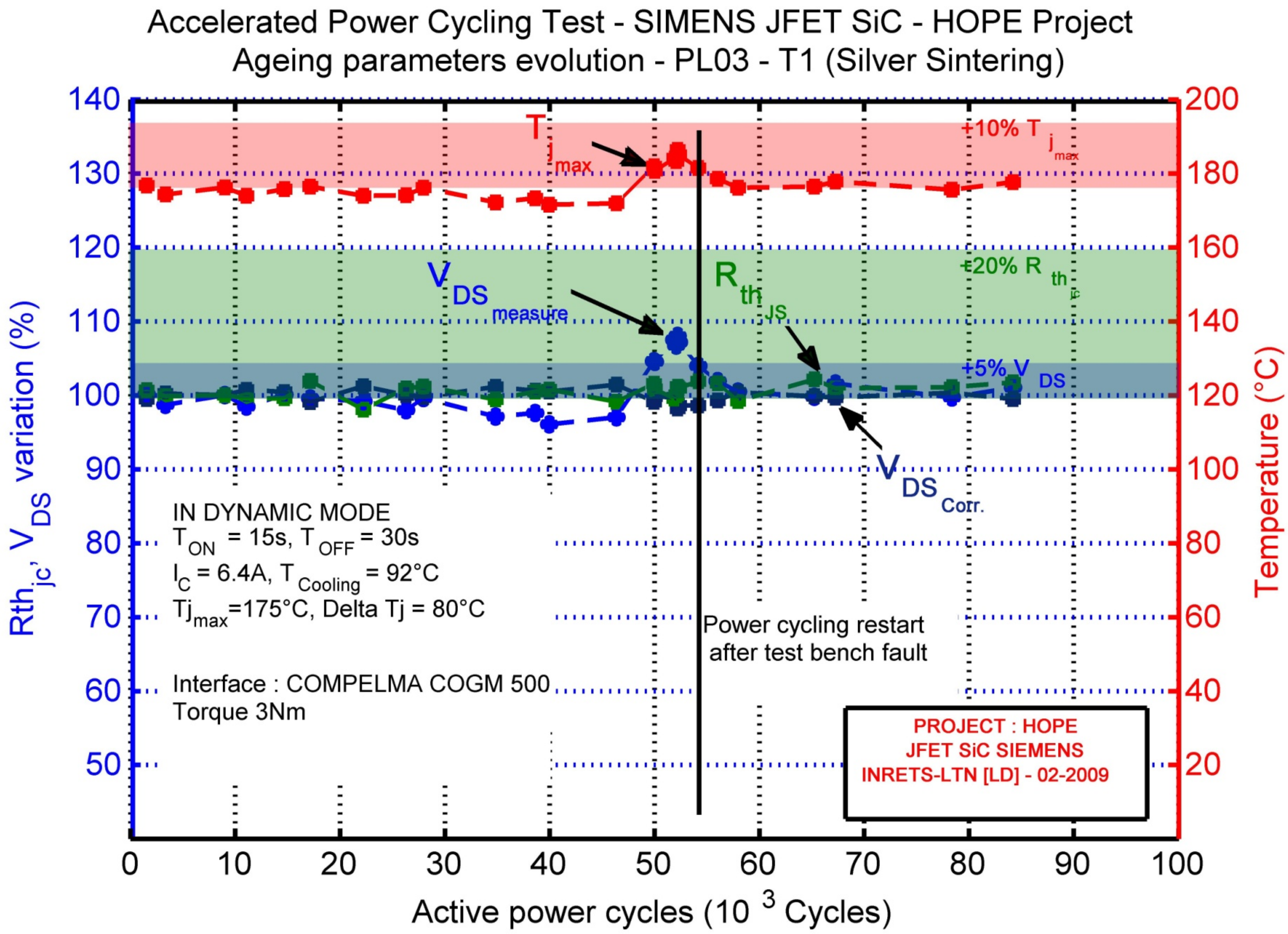
Figure 9.1 Robustness Validation Intelligent Testing Temple

Reliability Curve for Bond Wires by Power Cycling



Source Infineon

Accelerated Power Cycle Test Results



Experiments done by INRETS

Accelerated Test for Al Thick Wire Bond Lift-off

The overall acceleration can be estimated as:

Assumtion:
Operation time = 10.000 h → 30.000 NEDC

Acceleration factors:
•Thermal **→ 4**
•Time compression: There are 36 accelerations and decelerations within one NEDC;

power cycle test which is 4s on and 4s off **→ 4**

Test time with **acceleration of 16**: → **26 days**

Test Requirements for Mild Hybrid

	Occurence	Thermal Equivalent (%)	Number	Equivalent Powercycles @ Imax
Cold Start	2 times a day	175	10500	100195
Warm Start	2 per km	66	1300000	118519
Normal driving	every 10 seconds	55	19200000	348940
Boost 1	1 per km	66	300000	59259
Boost 2	1 per km	90	300000	204904
Boost 3	every 5 km	100	60000	60000
Total				**891817**

Assumptions for the mission profile:

15 years lifetime, 2 drives per day, 300.000 km, 10590 hours operation

Thermal equivalent normalized to maximum boost current

The Robustness Validation Process Flow

1. **Determine/ Define Application**
2. **Define Application Mission Profile**
3. **Develop Module Requirements**
4. **Identify Key Risks and Failure Mechanisms**
5. **Create Robustness Validation Plan**
6. ***Robustness Analysis of Manufacturing Processes***
7. **Execute Robustness Validation Plan**
   ASM (Analysis, Simulation and Modelling)
   Intelligent Testing

Conclusions

1. **Two handbooks on Robustness Validation are available, one for components and the second on electrical/ electronic modules**

2. **The handbooks provide just guidelines. A lot of work is needed to:**
   - Translate the mission profile of the vehicle to the stresses applied to modules and components
   - Build-up the knowledge matrix for dominant failure mechanisms, physical failure models, experimental parameters, etc. to carry out life-time predictions
   - Design intelligent end-of life tests to find out which part of the system fails first

3. **A strong concerted action of all partners in the supply chain is needed to make robustness validation applicable**