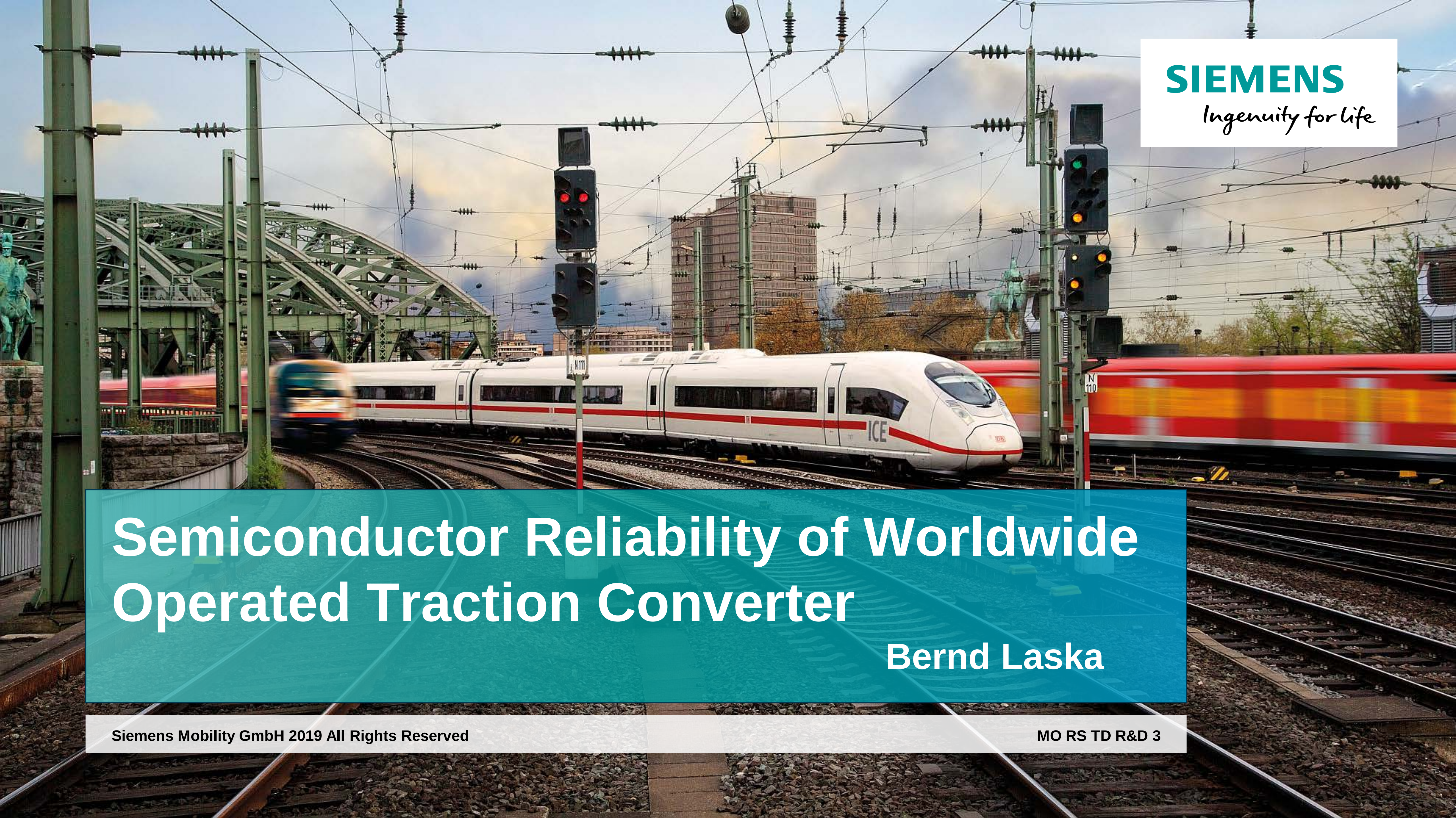

SIEMENS
Ingenuity for life

Semiconductor Reliability of Worldwide Operated Traction Converter

Bernd Laska

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ECPE Railway Working Group Members

Infineon, ALSTOM, SNCF, ECPE

Mitsubishi Electric, Changes for the Better, SIEMENS, DB, Fuji Electric

ABB, BOMBARDIER

HITACHI Inspire the Next, CAF Power & Automation

In cooperation with the European PINTA Project in the Shift2Rail Joint Undertaking

Shift2Rail, PINTA

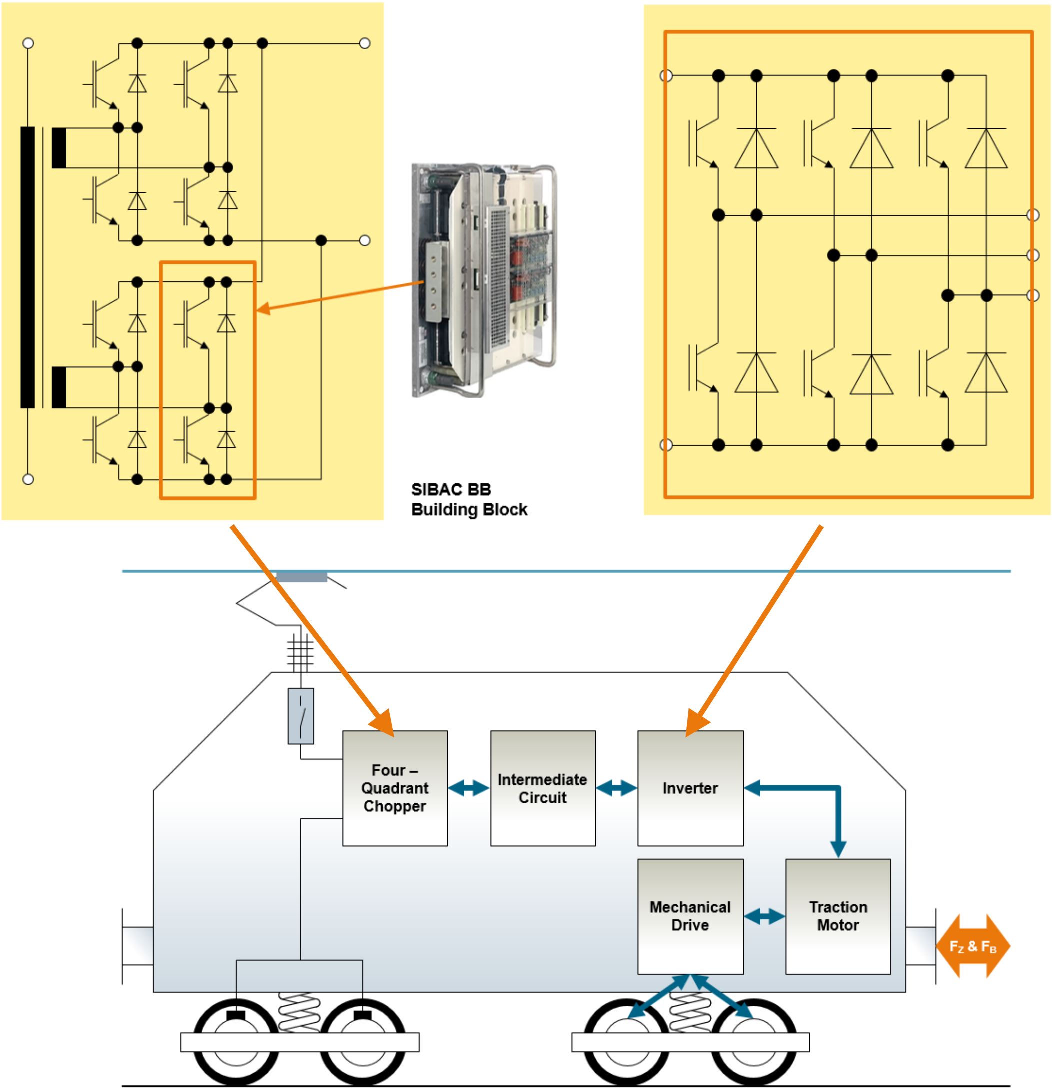
Typical Rolling Stock
High-Performance Locomotive Vectron

Traction system architecture

- Four independent drive system (BoBo)
- Supply systems: AC15kV, AC25kV, DC3kV, DC1,5kV
- Converter function:
  - Four quadrant chopper (4QC)
  - Inverter
  - Brake chopper
  - Step-up chopper

Number of semiconductor devices per locomotive

- IGBT- Module (single switch): 68
- DCB: 384
- Si- Chips (IGBT and diode): 2304
- Semiconductor area (silicon): appr. 0,4 m²



Generic Train Operation compared with Private Cars (Automotive)

Schedule and Lifetime Requirements

Operation	Rolling Stock (Commuter, mean) [1)]	Private Car [2)]
Lifetime [a]	40	17
Mileage per year [Mio km]	6	0, 42
Starting cycles per day	7	2
Environmental temperature [°C]	-40 °C … + 70°C (85 °C)	-40 °C … + 85 °C
Operating days per year	310	
Operating time [h]	124.000	12.000
Standstill with power supply [h]	49.600	
Standstill w/o power supply [h]	124.000	136.920

[1)] PINTA, subproject of the European founded Project Shift-2-Rail, 2017 & 2018 – **operation strongly depends on the operator**
[2)] Dr. Tiederle, Zuverlässigkeitsprognosen von Bauelementen, 11. Europäisches Elektrotechnologie-Kolleg, April 2008

Development and introduction of new technologies require accelerated lifetime tests and lifetime models which allow a lifetime forecast for different operational scenarios depending on the schedule, operation and environment.

Technical scope of the ECPE working group

Technical scope of the working group

Semiconductor type
Si, SiC, GaN

Basic Standards
IEC 60721
EN 50125
IEC 60747
etc.

Semiconductor Housings
Multi-chip module,
discrete,
press-pack

Climatic regions
Full- or limited scope of
IEC 60721-2-1

Physical impacts
Temperature/ humidity,
Condensation,
chemical substances
PC & TC,
shock & vibration

Applications
Vehicle type,
installation location:
roof, underfloor,
machine room

Observation and Evaluation of Field Failures

Lifetime Models, Example for the Failure Mechanism Corrosion

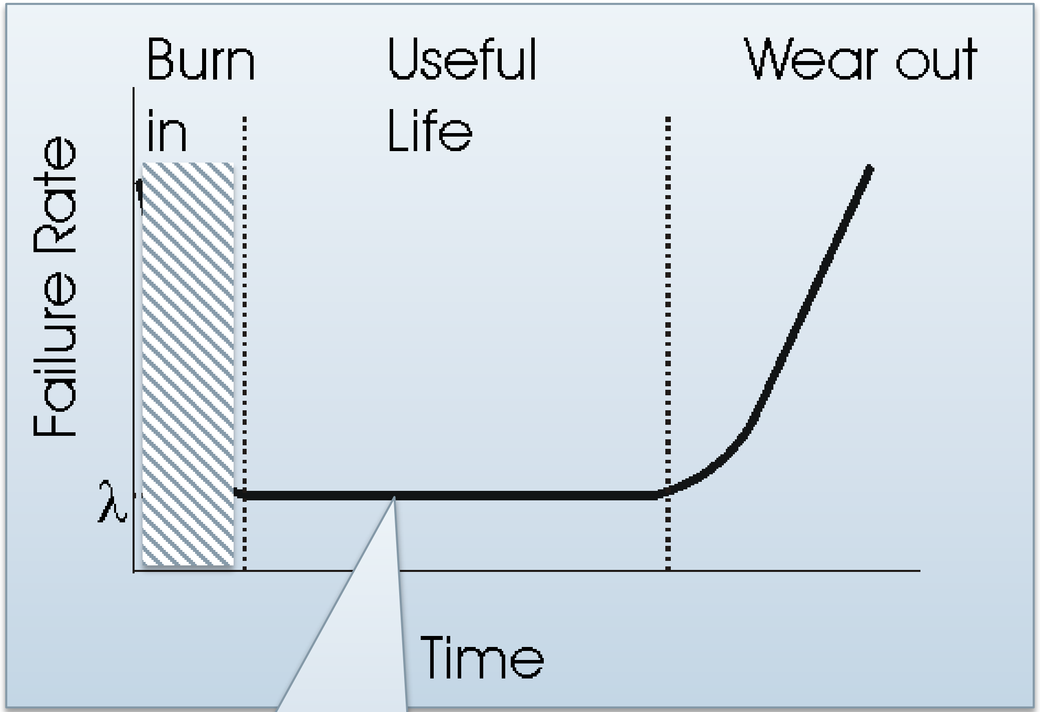
Reliability, corrosion failure mechanism

$$R_{cor} = R_{0_{cor}}(AF_{cor})$$

$$AF_{cor} = \exp\left(-\frac{Ea_{cor}}{k}\left(\frac{1}{T}-\frac{1}{T_a}\right)\right) \cdot \left(\frac{RH_a}{RH}\right)^{x_{cor}} \cdot \left(\frac{V_a}{V}\right)^{y_{cor}}$$

K= constant of Boltzman (8,617 e^{-5})

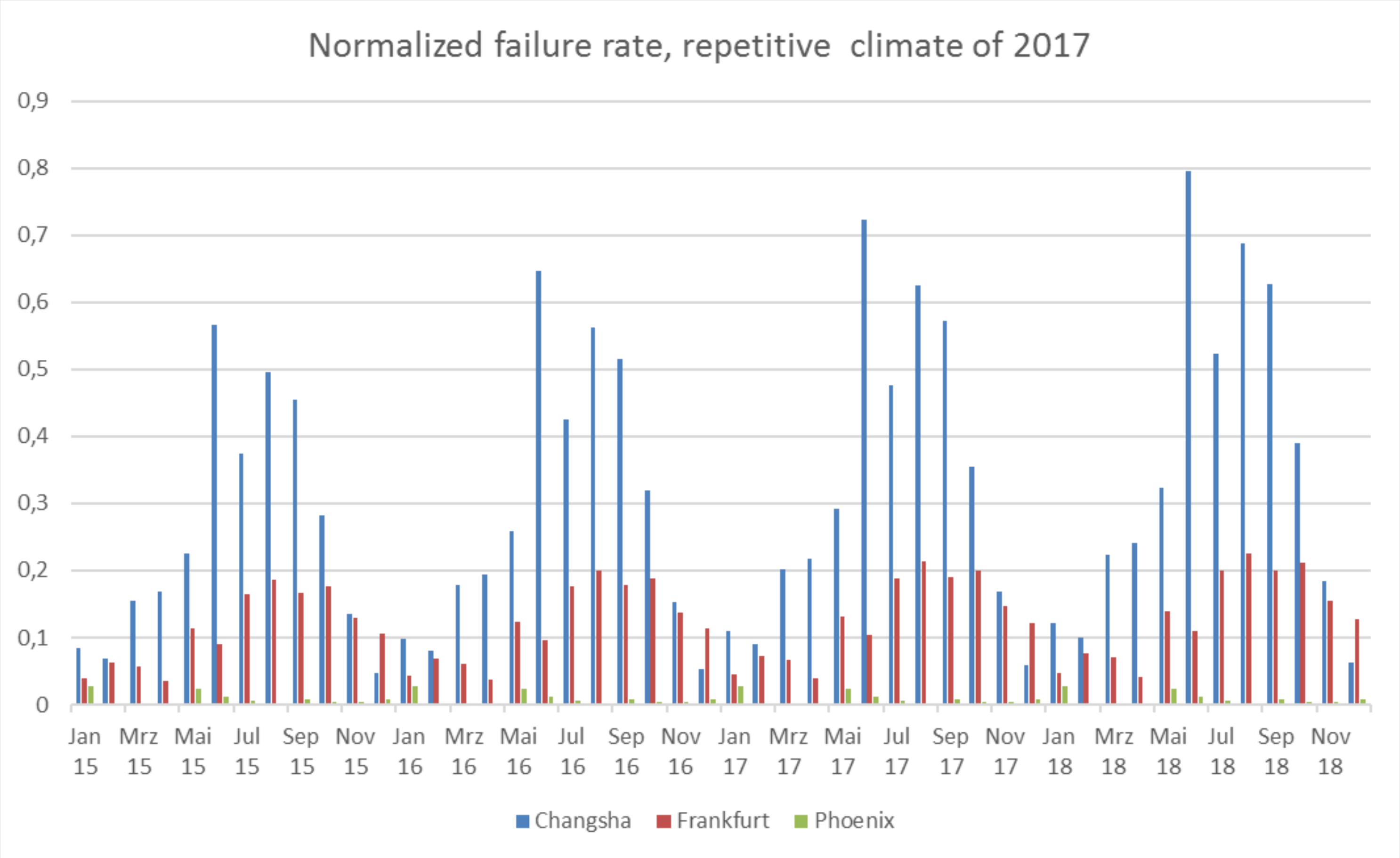
$\mathbf{R_{cor}}$	Reliability
$\mathbf{AF_{cor}}$	Acceleration Factor
$\mathbf{Ea_{cor}}$	Activating energy
RH	Relative humidity



Have closer look !

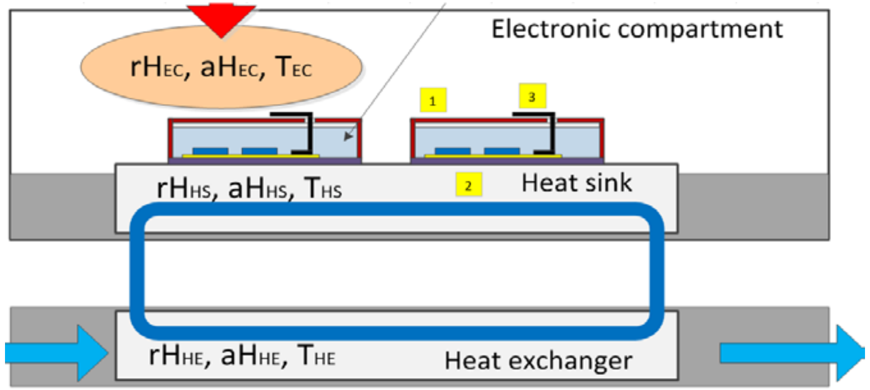
Resulting Failure Rates at Different Locations Worldwide

- Field failure rates caused by corrosion failure mechanism depend strongly on the environmental conditions.
- Same equipment will show different failure rates depending on the region.
- Failure rates will vary depending on seasonal climatic changes. i.e. in warm and humid summer seasons failure rates could be significant higher.



Lifetime models are needed for reliability engineering based on a precise understanding of the failure mechanism

Generic Train Operation
Use Cases with Possible Condensation



1. **Requirement Specification**
   Environmental requirements for power electronic used on Rolling Stock
   - Warm and humid climate, condensation in converter cabinets
   - Chemical environmental requirements

2. **Data validation**
   a) **Evaluation of microclimate data measured on vehicles**
      - Define a measurement equipment for an improved data acquisition
      - Measure data for different vehicle types and regions
      - Transform measurement data into traction specific environmental requirements

   b) **Microclimate simulation model**
      - Development of a simulation model suited for the transformation of the external climate into the cabinet internal microclimate – extrapolation of measurement data to requirements

--------------------- ECPE working group with semiconductor supplier -----------------

3. **Development of lifetime models for semiconductor devices**

4. **Reliability test specifications as immediate measures**
   - Define new specific test specifications (HV-H3TRB, condensation / material migration test)

Approach to ensure dissemination and consensus

Use Cases → Environmental Requirements → Verification/ Validation → Standardization

Scope of Roll2Rail and Shift2Rail/Pinta

Approach/ Target

- Define operational use cases with an impact on the container internal micro climate
- Identify the relevant requirements for the power semiconductor modules installed in the electronic compartment.
- **Validate requirements with data from vehicle measurements considering the impact of installation locations**
- Climatic requirements shall be used as a design and qualification basis as well as for qualification tests for the devices
- Specifications will be prepared as ECPE Technical Guideline planned to be submitted to standardization bodies.

Achievements

Reliability test specification was issued as an Europe wide public avaliable ECPE guide line.

A test specification for condensation effects in semiconductor devices internal is in preparation.

TECHNICAL SPECIFICATION

October 23rd, 2019

Railway applications
HV-H3TRB tests for Power Semiconductor

Campaign	Type of Rolling Stock	Operator	Loca-tion	Max. Speed (km/h)	Working Hours	Converter type	Cooling type	Converter location			Measured Positions			Track character-istics		Add. Data	
								Roof	Underfloor	Machine Room	Close to module	Heatsink	Outside of Cabinet	Tunnel sections	Operational height	Vehicle Status Data	GPS
CITYJET ECO (SIEMENS)	Regional, Intercity	ÖBB	Austria	160	16	DC/DC Motor inverter	Water										
ICE 4 (SIEMENS)	Intercity	DB	Germany	230	18	Motor inverter	Water										
Regiolis (ALSTOM)	Regional	SNCF	France	Max 160	10 to 16	Motor Inverter	Water										
Twindexx Vario BR446 (BOMBARDIER)	Regional, Double deck	DB	Central Germany	160	16 (Specified)	Motor Inverter	Water										
EUSKOTREN (CAF)	Regional, Intercity	CAF	Spain (Basque Country)	90	15	Motor Inverter	Natural cooled										
UBx (Siemens)	Metro	Wiener Linien	Austria	80	Tbd.	Auxiliary Inverter	Force Cooled										
Avenio (Siemens)	Tram	SWM	Germany	70	18	Motor Inverter	Force Cooled										

Measurement locations for harmful gas requirements

	Location	Partner	Contact person	Status
Germany	Nuremberg	Siemens	Dr. Bernd Laska	Measuring in progress
	Ratingen	Mitsubishi	Eugen Wiesner	Transport and installation
	Halle	Fraunhofer IMWS	Klegel Sandy	Transport and installation
	Ostfilden-Kemnat	Wevo-Chemie	Terence Kerns	Transport and installation
Europe	Paris (FR)	Schneider Electric	Philippe Loizelet	Transport and installation
	Rennes (FR)	Mitsubishi	Andreja Rojko	Export management
	Cornella (ES)	Siemens	Dr. Bernd Laska	Export management
	Cartagena (ES)	Ayuntamiento de Caragena	Pedro Yepes Martinez	Export management
	Maidenhead (UK)	Hitachi	Chris White	Measuring in progress
	Milan (IT)	Alstom	Mantoan Gianni	Export management
	Lyngby (DK)	TU Denmark	Prof. Rajan Ambat	Export management
	Tallinn (ES)	Doranova Oy	Mati Fjodorov	Applying for permission
	Krakow (PO)	ABB	Maciej Orman	Applying for permission
	Helsinki	ABB	Kjell Ingman	Applying for permission
Laboratory IISB	Erlangen (DE)	Fraunhofer IISB	Weiyi Chen	Measuring in progress

Objective:
Harmful gases with chlorine and hydrogen-sulphide content

- Maidenhead in the UK

Share of Responsibilities

Semiconductor Supplier and Converter Manufacturer

- A clear and technical oriented share of responsibilities between converter and semiconductor manufacturer is required.
- Converter manufacturer are responsible for complete and valid requirements derived from their application and mission profile.
- Test and qualification strategies require a detailed knowledge on technologies and materials used in the semiconductor devices.
- Semiconductor suppliers are therefore responsible for the definition of tests and acceptance criteria.

Converter manufacturer

Requirement specification

- Electric
- Mechanical
- Environmental conditions
- Isolation
- Lifetime
- Operation
- Etc.

Power semiconductor supplier

Semiconductor characteristics

- Electric characteristics
- Mechanical Properties
- Robustness and sensitivity against environmental conditions
- Materials & technologies
- Etc.

FMEA and Risk Analysis

Mission Profile → Risk Evaluation ← Verification Tests

Responsibility: Correctness, completeness of requirements

Responsibility: Tests and acceptance criteria

Summary and Outlook

- **Climatic conditions with high humidity and high temperatures can significantly reduce traction system reliability.**
- **Power semiconductor design has to be robust against “outdoor” environmental conditions including condensation.**
- **A clear understanding of the rolling stock operation and environmental loads is needed for the definition of representative mission profiles.**
- **Accelerated tests have to be developed by the semiconductor suppliers based on the mission profiles. Reliability engineering needs accurate lifetime models.**
- **EU Project PINTA plans a comprehensive measurement campaign on vehicles to measure environmental conditions close to the power semiconductors.**

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