Robustness Validation for MEMS

Electronic Components and Systems Division

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- Appendix to the Handbook for Robustness Validation of Semiconductor Devices in Automotive Applications

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Preface

The “Handbook for Robustness Validation of Semiconductor Components in Automotive Applications” was published by ZVEI in April 2007. Although this handbook is generic, it is mainly based on consideration of standard integrated circuits.

MEMS sensors build up a special category of devices that need specific considerations. By their very nature, MEMS sensors are often exposed to harsh environmental conditions that are in an obvious way not covered by standard stress test conditions used in product qualifications. Neither commonly referenced product qualification standards nor the Robustness Validation handbook adequately represent the sensor needs. It is for this reason that sensor manufacturers joined in a team organised by ZVEI to discuss the application of Robustness Validation to sensor devices.

This publication is an attempt to elucidate the application of Robustness Validation to MEMS sensors. It is also generic in its approach. It can not and is not intended to deal in detail with the manifold of types, technologies and applications that comprise the whole field of MEMS sensors. Instead, it addresses specific aspects of the Robustness Validation approach in the context of MEMS sensors and also tries to illustrate, why straightforward transfer of certain aspects presents some difficulties.

It is hoped that this document will be helpful in advancing the robustness of MEMS sensors and the methods to prove this robustness.

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CONTENT

1. Introduction

Robustness Validation is a valuable approach in product development and qualification. In contrast to standard qualification real application conditions are reflected. The ”Handbook for Robustness Validation of Semiconductor Devices in Automotive Applications” [1] presents a new qualification approach for semiconductors and is the basis for further discussion in this appendix.

The basic principles of Robustness Validation are described in the Robustness Validation flow below (see Figure 1-1). The flow starts with the mission profile which summarises all product requirements. The requirements given in the mission profile have to be compared to the capabilities of the product/technology under consideration in a risk assessment. For standard semiconductor components a commonly accessible knowledge matrix [4] with known failure mechanism and causes can support such a risk assessment. Based on the risk assessment the qualification plan will be generated. The robustness is derived from the qualification test results. If the robustness is sufficient, the product can be released for production. Contrary to a product release based on standard qualification procedures, Robustness Validation leads to a release with respect to a certain documented mission (requirement) profile.

Figure 1-1: Robustness Validation flow

MEMS sensors are characterized by highly complex technologies, complex packages and harsh environments during application. The following figure gives an impression about the wide variety of MEMS devices and their application.

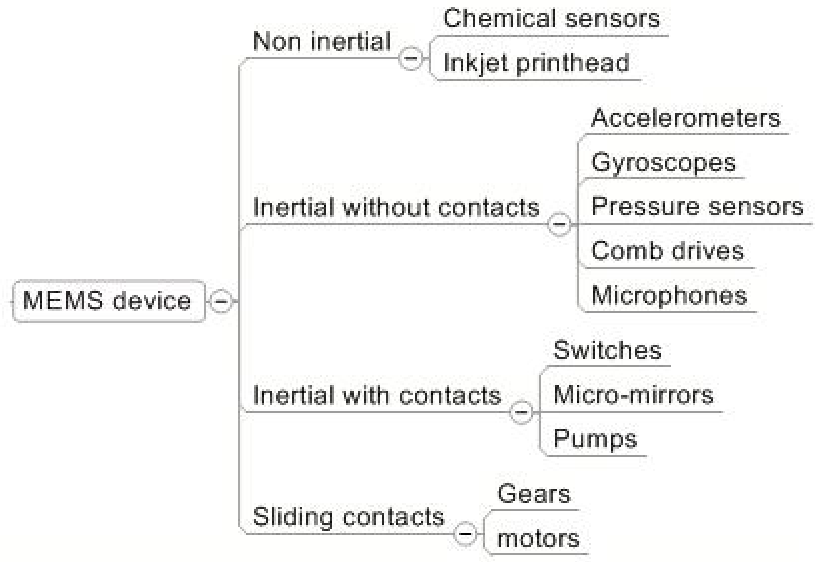


Figure 1-2: MEMS categories showing the wide variety of devices

This wide variety of MEMS sensors leads to specialised technologies to support certain applications. Most of the knowledge about these technologies is protected IP and not published. Therefore, an expert team within ZVEI elaborated the Robustness Validation approach for MEMS based on the handbook for semiconductor devices by focusing on the topics which have to be considered under the special boundary conditions of MEMS sensors. These topics are mission profile, knowledge matrix and accelerated testing.

The chapter “Mission Profile” demonstrates the way how to generate a mission profile. Ideas about the degree of details necessary for Robustness Validation are provided. A template to support generation of the mission profile is provided in the annex and as Excel file on the enclosed CD.

The challenges due to the large variety and specialised IP protected knowledge is discussed in the chapter “Knowledge Matrix”. A classification of MEMS sensor devices that can be used in a knowledge matrix is presented. In contradiction to standard semiconductors it is not intended to publish a general knowledge matrix. Rather the provided knowledge matrix should serve as an example how such a matrix could be set up.

The chapter “Accelerated Testing” describes available qualification tests. Discussions of these tests revealed that it is useful to categorise them in wear out, overload, characterisation and application tests. Only limited lifetime and acceleration models are available for MEMS sensor specific tests. Without such models no clear relation of test conditions to application requirements can be established (see **Figure 5-1** in chapter “Accelerated Testing”). This is an additional challenge for robustness validation of MEMS sensors. Suggestions how to handle these obstacles are discussed.

Although much of this may sound as if application of Robustness Validation to MEMS sensors is fraught with difficulties, it has to be emphasised that Robustness Validation will lead to a better mutual understanding of requirements and boundary conditions, better design of products and, at least in the long run, to better reliability/robustness assessment.

With this appendix we intend to support the introduction of Robustness Validation to MEMS.

2. Terms, Definitions and Abbreviations

2.1. Terms and Definitions

Term	Definition
Accelerated test	A test using test conditions that are more severe than usual operating conditions.
Acceleration factor	The ratio between the times necessary to obtain the same portion of failure in two equal samples under two different sets of stress conditions, involving the same failure modes and mechanisms.
Commodity product	A semiconductor component that is not developed for a specific customer and/or application.
Component life cycle	Time period between the completion of the manufacturing process of the semiconductor component and the end of life of the vehicle.
Component mission profile	A simplified representation of all of the relevant conditions to which all of the production devices will be exposed in all of their intended application throughout the full life cycle of the semiconductor component.
Defect	A deviation in an item from some ideal state. The ideal state is usually given in a formal specification.
Degradation	A gradual deterioration in performance as a function of time.
Device	An item (or part of a system) with well -defined features.
ECU Level	Level of the Electronic Control Unit (system).
Electrical/electronic module - EEM	Electrical stand alone modules with electrical and/or optical interface. The EEM typically consists of housing, connector, conductor boards and electrical components. Typical example: Motor management systems. Mechatronics integrate mechanical and electrical functions into one unit. The mission profile of this solution has to respect both parts. In vehicle applications typical mechatronic products cannot be exchanged independently from electronics. Typical examples: ABS, EPS (Anti Lock Braking System, Electrical Power Steering).
Electronic component	A self-contained combination of electronic parts, subassemblies, or assemblies that perform an electronic function in the overall operation of equipment.
Failure	The loss of ability of an EEM to meet the electrical or physical performance specifications that it was intended to meet.
Failure mechanism	The physical, chemical or other process that results in a failure.
Failure mode	The effect or manner, by which a failure is observed to occur, is the effect of the failure mechanism.

Lifetime	The time span between initial operation and failure.
Load	An externally applied and internally generated force that acts on a system or device. The application of loads results in stress and strain responses within the structures and materials of the system or device. Loads may by mechanical, thermal, electrical, radiation or chemical in nature or any other form of physicality.
Load distribution	Statistical distribution of load levels over e.g. time, cycles, temperature, voltage, climatic conditions, and other load types. It should represent different use cases.
Model	A simplified representation of a system or phenomenon, as in the sciences, where a hypothesis (often mathematical in nature) is used to describe the system or explains the phenomenon.
Operating conditions	Conditions of environmental parameters, voltage bias, and other electrical parameters whose limits are defined in the datasheet and within which the device is expected to operate reliably.
Product life	The time period from the beginning of the manufacturing process of the electrical/electronic module to the end of life of the vehicle.
Qualification	The entire process, by which products or production technologies are obtained, examined and tested, and then identified as qualified.
Reliability	The ability of a system or component to perform its required functions under stated conditions for a specified period of time [IEEE 90]
Robustness validation	A process to demonstrate the robustness of a semiconductor component under a defined mission profile.
Semiconductor component	A single or a collection of active and passive devices (for example, transistors and resistors) produced on a semiconductor as base material and packaged as a single component. Electronic conduction primarily takes place within the semiconductor material.
Simulation	The representation of the behaviour or characteristics of one system through the use of another system, especially with a computer program designed for the purpose of simulating an event or phenomenon. The technique of representing the real world by a computer program; such that the internal processes of a system are emulated as accurately as is possible or practical and not merely mimicking the results of the thing being simulated.
Stress factor	A stress or combination of stresses which triggers a failure mechanism.

Validation	The process of accumulating evidence to support a declaration with legal force that a system/module/component meets the known application requirements. Validation culminates in producing a formal declaration with legal weight that a product has been confirmed supported by objective evidence that the requirement for a specific intended use have been fulfilled. Tests have a defined success point that becomes the base measurement for the "Robustness Validation" phase.
Verification	The conclusion of the primary product development learning process supporting progress to the legal validation phase that the product has a high probability for meeting all known application requirements. There are no legal ramifications in verification. Learning may occur with test to failure for capability measurement beyond the established requirements and reliability demonstration.

2.2. Abbreviations

AEC	Automotive Electronics Council
ESD	Electrostatic Discharge
EMC	Electromagnetic Compatibility
EOS	Electrical Overstress
IC	Integrated Circuit
IP	intellectual property
MEMS	Micro Electrical Mechanical System
PCB	Printed Circuit Board
TPMS	Tire Pressure Monitoring System
ZVEI	Zentralverband Elektrotechnik- und Elektronikindustrie e.V. (German Electrical and Electronic Manufacturers´ Association)

3. Mission Profile

The mission profile is a representation of all relevant conditions a MEMS sensor can be exposed to in all of its intended applications throughout its entire life cycle. It is therefore important that the mission profile for each individual MEMS sensor should be developed and communicated as early as possible to the engineers designing the sensor. With a good description of the mission profile, engineers can begin to estimate reliability and quality levels and start to work toward achieving robust design at all levels of the supply chain.

Good mission profiles are based on long experiences, with the application as well as with the applied technologies. As in many cases the realization and technology of the electronics is defined after studying the first mission profile “frame”, the creation of the mission profile is an iterative process (see **Figure 1-1**). All the relevant parameters to be defined in the mission profile are known, only after definition of the applied technologies.

For example if speed measurement on the wheel is realized with a Hall sensor, the magnetic environment has to be well defined. In case of realization with an optical sensor, the magnetic environment does not concern at all but the conditions which influence light transmission are now important to be clarified.

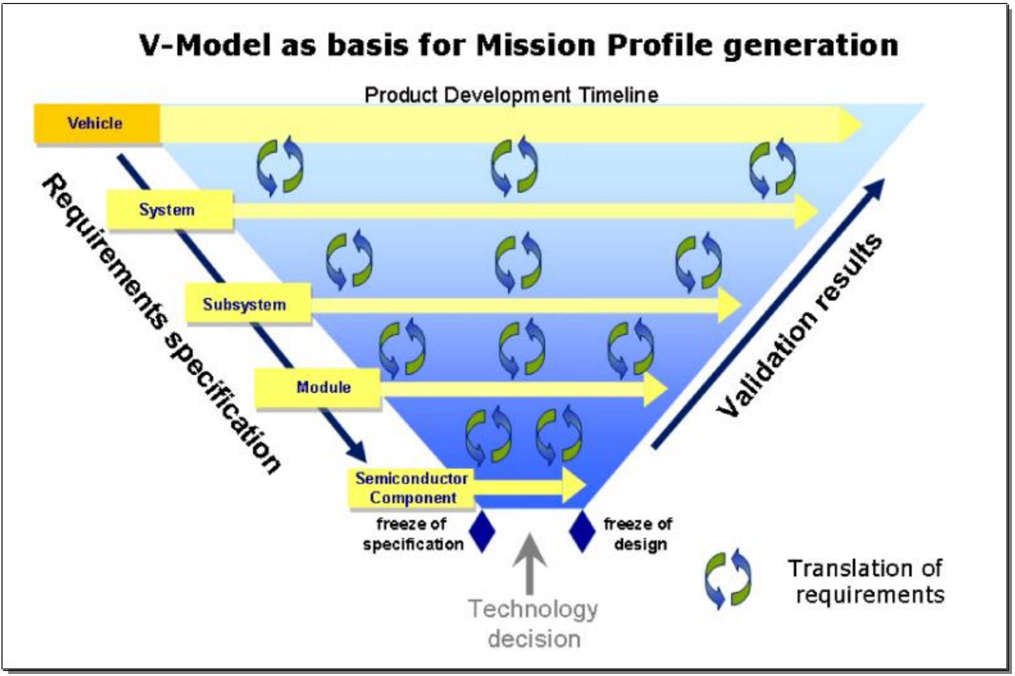


Figure 3-1: Development V-cycle

This chapter provides an overview of the various conditions and stress factors (loads) a MEMS sensor may experience during its life cycle. This information is intended to be used as a starting point in developing mission profiles for an individual MEMS sensor. Stress factors may be mechanical, climatic, chemical and electrical loads during manufacturing, operation, stand by and at transport of the sensor and car assembly. As shown in **Figure 3-2** the stress factors may be due to environmental loads, functional loads or both simultaneously.

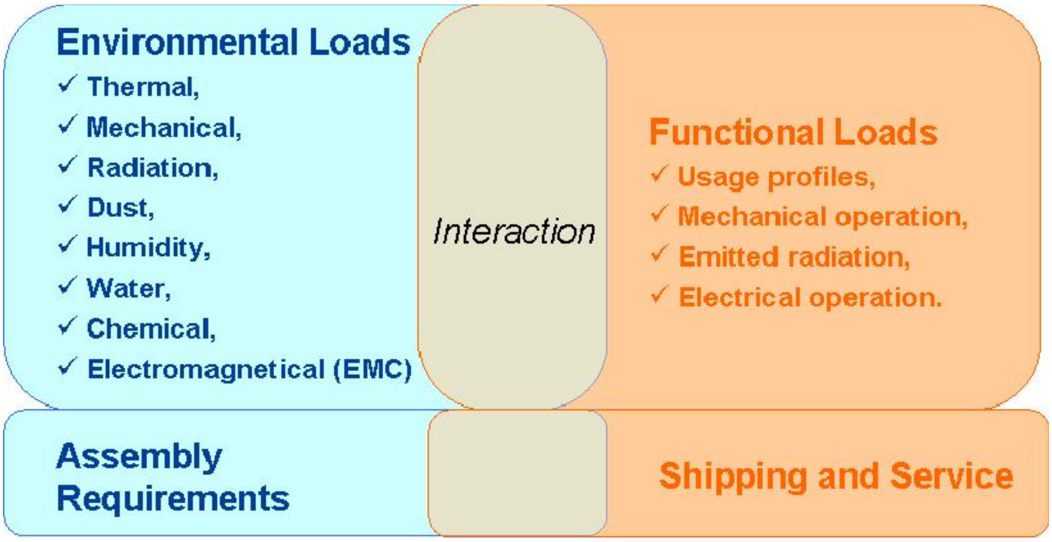


Figure 3-2: Environmental and functional load stress factors

Environmental loads are external stress factors caused by certain environmental conditions, such as temperature, humidity, etc. Functional loads are stress factors caused by Sensor/EEM operation, usage profiles etc.

Environmental loads should be selected from the following tree and/or added when necessary for a specific mounting location. Relevant loads have to be described including their detailed conditions.

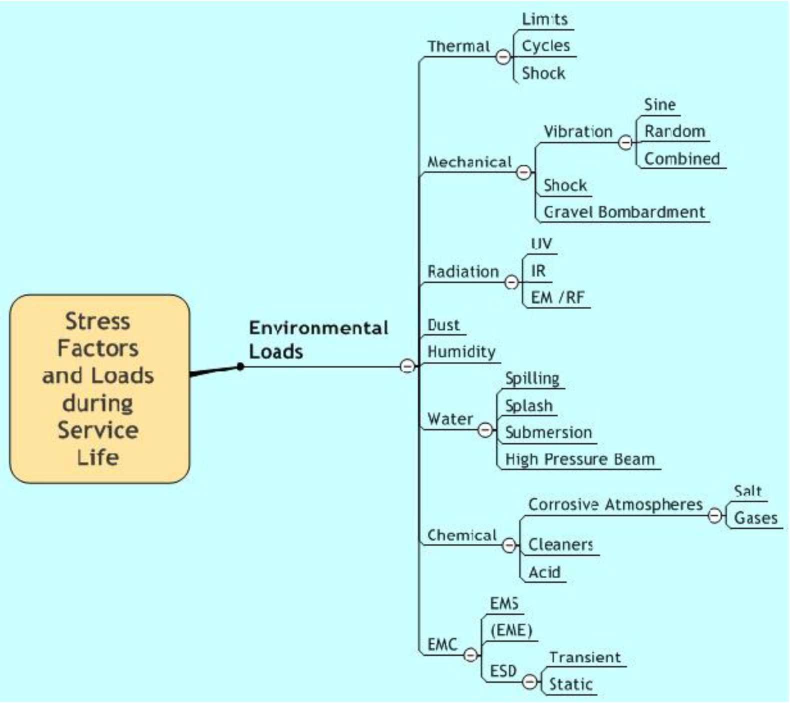


Figure 3-3: Tree analysis of environmental loads

Functional loads for a specific MEMS sensor technology and application should be selected from the following tree and/or added when necessary. Relevant loads have to be described including their detailed conditions.

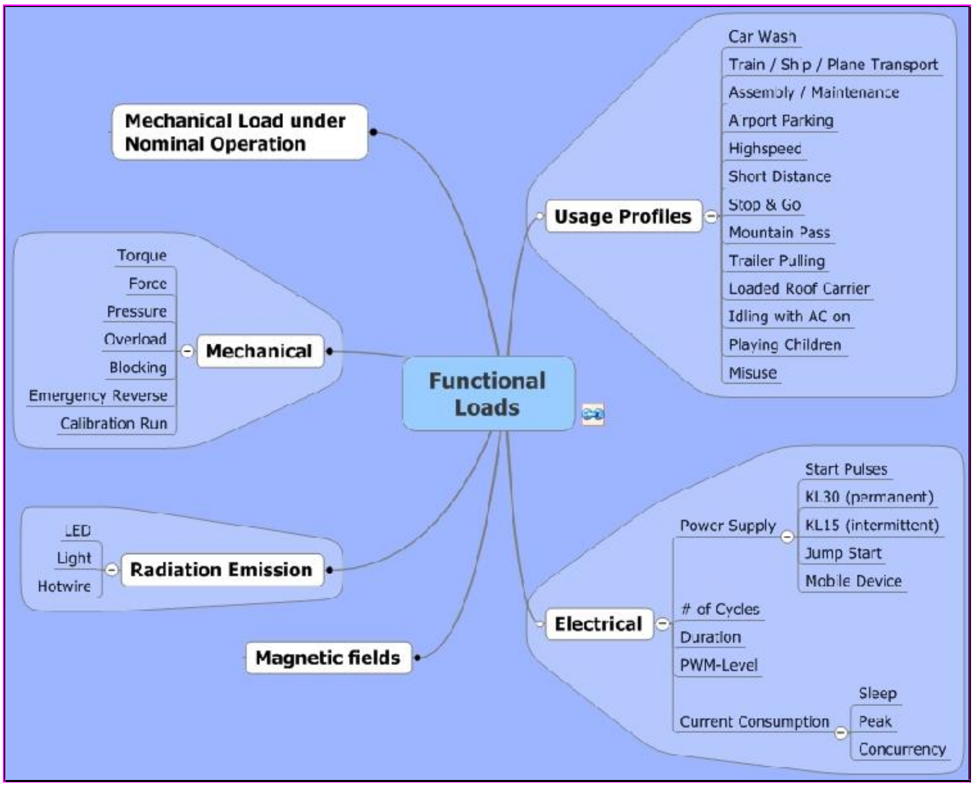


Figure 3-4: Tree analysis of functional loads

As the product development process progresses, mission profiles and functional loads will be defined more precisely. Therefore, changes and revisions to loads or load distributions shall be agreed upon between the parties.

The mission profile is not a test description. It is the basis for test engineering, parameterization, analysis, modelling & simulation, and robustness evaluation.

3.1. Process to Derive a Mission Profile

3.1.1. Simplified description how to get a first mission profile (left branch of the V-cycle):

1. Write down all environmental conditions of the final product (e.g. vehicle) as physical loads including lifetime requirements. Use templates (mindmaps, excel table) as attached.
2. Check for each level down (vehicle => mounting area => electronic module => PCB => component….) if these conditions are getting more or less severe and under which conditions (use cases!)
3. Add loads due to functional requirements (examples see attached mindmaps)
4. Define a technical solution (technologies, packaging, functionality)
5. Check how the technical solution changes the loads (e.g. by power dissipation)
6. Check the loads list if it contains all physical parameters the technical solution is sensitive to.

7. Check now the complete process chain (from delivery of the component until the vehicle is in the field) for additional loads
8. First draft of the mission profile is now available

With this mission profile we have the basis for a first Robustness Assessment, where we compare the mission profile with the known characteristics of the planned solution. If the robustness is too small or too large we have to optimize the technical solution or change the requirements (e.g. tight housing in case of sensitivity to media). Finally tests have to be defined to be able to check the mission profile requirements on the technical solution (s.a. chapter Accelerated Tests and Knowledge Matrix).

3.1.2. Typical approach to generate and check a mission profile

When developing a mission profile, it is likely that multiple sources of data will be utilized. Knowledge of the conditions of use in the vehicle application(s) and the possible effects on the module and the sensor is required. Because some factors may have little effect while others may have a strong effect, it is also necessary to judge the relevance of each factor.

STEP 1 - Start with vehicle service life requirements

The most general data concern the required vehicle service life. First the vehicle type (passenger or commercial vehicle) should be clarified then the service life requirements comprise information as for example:

Service lifetime:	The total expected lifetime of the car. (e.g. 10 years, 15 years)
Mileage:	The total amount of miles/kilometres that the car is assumed to drive during its service life. (e.g. 200 000 km to 600 000 km)
Engine on time:	The amount of time that the engine is switched on (key-on time) and operational during the service lifetime (if product is active during this time). Expected operating hours can be e.g. 4 000 h to 12 000 h

An example of this kind of data is given in **Table 3-1** below.

Service life time	Mileage	Engine on time	Engine on/off cycles
15 years (=131 400 h)	600 000 km	12 000 h	54 000
	High level high mileage request for stand alone EEM (not for mechatronics)	Engine on time is directly proportional to mileage. Operating time of single sensor may be different than engine on time.	Without additional start/stop functions

Table 3-1: Example of vehicle mission profile parameters at the vehicle level.

STEP 2 - Translate to next level: EEM / Mechatronic life time requirements (OEM)

The above definitions are valid for the whole vehicle. However, depending on the functionality required, the active and passive periods may be very different for the EEM compared with vehicle requirements. Their different service life requirements are exemplified in **Table 3-2** below.

Vehicle	EEM
Engine on time	EEM on time (operating, active)
Engine off (non-operating time)	EEM off time (non-operating) EEM standby time
Engine on/off cycles	EEM on/off cycles

Table 3-2: Different service life requirements for vehicle and EEM

Furthermore, for the mission profile of the EEM, the mounting location and specific use cases have to be considered. Therefore, for each EEM/Mechatronics, the active, stand-by, sleep and non-operating time must be determined individually.

Step 2.1: Collect possible operating modes (active, stand-by, special loads, sleep, power supply interrupted, cyclically reoccurring operation, and operating mode changes)
Each relevant function must be completely covered.

Step 2.2: Assign operating modes to the defined vehicle lifetime requirements.

Step 2.3: Describe mounting locations, conditions and related loads:
Temperature (Distribution)
Temperature cycling (Distribution)
Vibration (Distribution)
Water, salt, dust, humidity, chemical agents
Detail load profiles (e.g. electrical/thermal/mechanical loads) of the EEM/Mechatronic (experience from present projects).

Result: Basis for mission profile for EEM/Mechatronic

Consider: Misuse, safety requirements, transport, storage, service (EOS/ESD), processing/assembly, testing.

An example of this kind of data for EEM level is given in **Table 3-3** below.

	Operating on time (active) (h)	Non operating time (h)	EEM active on/off cycles	EEM specific operating load cycles
Motor-management	12 000 + 3 000 Standby time	116 400	54 000 Without additional start/stop functions	Engine on/off
Transmission control module	6 000	125 400		Gear shift
Door Module	8 000	79 800	36 000 + operating cycles Operating cycles: + window + mirror activation	Window lift

Table 3-3: Example of OEM EEM operating life time requirements

STEP 3 - Translate to next level: MEMS sensor life time requirements

The above definitions are valid for the vehicle and the EEM. However, depending on the functionality required, the active and passive periods may be very different for the vehicle versus the EEM versus the MEMS sensor. Their different service life requirements are exemplified in **Table 3-4** below.

Vehicle	EEM	sensor
Engine on time	EEM on time (operating, active)	sensor on time (operating, active)
Engine off (non-operating time)	EEM off time (non-operating) EEM standby time	sensor off time (non-operating) sensor standby time
Engine on/off cycles	EEM on/off cycles	sensor on/off cycles

Table 3-4: Different service life requirements for vehicle, EEM and MEMS sensors

Furthermore, for the mission profile of the MEMS sensor, the mounting location and specific use cases have to be considered. Therefore, for each sensor / Mechatronics, the active, stand-by, sleep and non-operating time must be determined individually.

Step 3.1: Collect possible operating modes (active, stand-by, special loads, sleep, power supply interrupted, cyclically reoccurring operation and operating mode changes)

Each relevant function must be completely covered.

Step 3.2: Assign operating modes to the defined vehicle/EEM lifetime requirements.

Step 3.3: Describe mounting locations, conditions and related loads:
Temperature (Distribution)
Temperature cycling (Distribution)

Vibration (Distribution)
Mechanical shock
Water, salt, dust, humidity, chemical agents and other media
Detail load profiles (e.g. electrical/thermal/mechanical loads) of the sensor/Mechatronic (experience from present projects),
consider all physical loads the sensor is sensitive to.

Result: Basis for mission profile for MEMS sensor/Mechatronic

Consider: Misuse, safety requirements, transport, storage, service (EOS/ESD), processing/assembly, testing, any physical load which can influence the sensor.

An example for life time requirements for a sensor level is given in **Table 3-5** below.

	Operating on time (active) [h]	**Non operating time [h]**	**sensor active cycles**	**sensor special operating load cycles**
Tire Pressure Wheel Unit	5 000	83 000 Standby time	Measuring cycles Transmission cycles	Learning mode, short cycle transmission in case of pressure loss, transport mode….

Table 3-5: Example of tire pressure monitoring sensor operating life time requirements

3.1.3. Estimation of mission profile for development of MEMS sensor

A first set of mission profiles is necessary to derive requirements for use in the development process (temperature limits for sensor and MEMS technologies selection, etc.). It shall describe the likelihood of the occurrence of loads with regard to the operation parameter range. However, an approximation can be given by:

Use standard mission profiles for defined mounting location.

Use measurements from previous developments.

Use measurements from similar applications / vehicles.

Estimate usage, generated by thinking possible use cases through.

To make sure that all parameters of any adopted mission profile cover the requirement for the specific mounting location, a validation of the chosen mission profile for the specific application is necessary.

3.1.4. Check use cases and use distribution (refinement and validation)

Define use cases

- Use cases can help identify sources of loads and provide operation parameters. By thinking through several use cases, choices of descriptive parameters, their distribution of values and severity of effect of failure can be outlined. Usually several relevant use cases can be combined into one enveloping mission profile thus enabling validation with the same plan.

Analyse use distribution

- Often sensor stress is significantly higher when operated close to the design limits (e.g. max. load). Also there are use cases that may result in unusually high load cycle numbers (e.g. taxi driver, rolling down a pass while braking).

Due to this, considering only possible limits/extremes may not be sufficient, additionally a use distribution is necessary. It shall describe the occurrence likelihood of loads with regard to the operation parameter range.

However, in the case that extreme distributions are ruled out from design considerations or test coverage, failures that may result there from these extreme distributions must still be evaluated for safety and customer satisfaction consequences. Furthermore it should be checked by thinking through use cases, if a combination of different loads can occur simultaneously or sequentially. For certain parts or materials these combinations may provoke different failure modes or accelerate others. Therefore a definition of combined loads may be necessary.

Example

Use case for sensor applications near vehicle brakes

Stop and go in the city, breaking every 200 m (high number of cycles, low load)

Highway singular power braking from 200 to 80 km/h (low number of cycles, high load)

Rolling down a mountain pass while continuously braking, then stopping the vehicle with red-hot brakes (low number of cycles, extremely high load)

3.2. Draft Mission Profile available

We have now a first complete draft mission profile for the MEMS sensor, on the V-cycle we are at the lowest point. The next step is to verify mission profile parameters and estimates by

- Translation back to EEM and vehicle mission profiles (check if sensor mission profile has an influence on mission profile of the upper levels
- Analyses of failure modes of the different levels with knowledge of the planned design and technology of the sensor
- actual measurements as parts / installations become available during the development process

The collected information on source/effect interaction should then be used for a qualitative analysis to identify parameters of the mission profile which do affect reliability of the system and rank them by assumed impact. This clarifies the significance of each parameter and helps in choosing an appropriate precision in its specification (e.g. requiring use studies, measurements, a fine-grained distribution or allowing rough estimation).

3.3. Agree on Mission Profile for MEMS sensors with Module Level Supplier

An ‘application questionnaire’ by the module level supplier shifts the focus to sensor and MEMS technologies intended for implementation and their critical conditions. The module level supplier should provide typical sensor oriented descriptions for environmental and operating conditions to finalize the MEMS sensor Mission Profile.

Discuss and agree mission profile for sensor with suppliers.

In the sense of Robustness Validation it is important to identify with the mission profile those important parameters which have a significant influence on the product reliability. It is also important to inform and sensibilize the other suppliers in the chain about these parameters to avoid that one of these parameters is changed without information of the concerned supplier(s) in the chain.

3.4. Examples for Mission Profiles / Loads

In the Annex you can find

- A detailed example for Tire Pressure Module Mission Profile
- An overview of functional loads for “Front Airbagsensor“ and “Wheelspeed Sensor“
- A template to generate your own mission profile

The template is also available on the “Robustness Validation for MEMS” CD.

4. Knowledge Matrix

In connection with the Robustness Validation Semiconductor Handbook [1] a so-called Knowledge Matrix [3] was created that contains information on failure mechanisms and testing relevant to integrated circuits. This Knowledge Matrix intends “to provide an overview of commonly accessible and acknowledged information on failure mechanisms and failure causes” and to “help component suppliers and users with the application of Robustness Validation and constitute a basis for communication between these partners” [1].

Creating such a knowledge matrix for MEMS sensors meets several difficulties.

- There exists a very large variety of MEMS sensors. This variety mirrors the large range of applications. Functional principles and technologies show corresponding large variations. This fact alone would render any intention of a reasonable coverage in a knowledge matrix futile.

- Most of the information pertaining to failure mechanisms is specific to the technology used and, therefore, of rather limited use to the general application of Robustness Validation.

- In addition, much of the information is subject to concerns about IP and, therefore, not published and not commonly accessible. This constitutes a significant difference between standard integrated circuits and MEMS sensors. Such a knowledge matrix can accordingly also not serve as “a communication basis” for suppliers and users.

An attempt was made to structure the wide variety of MEMS sensor devices, as shown in **Figure 1-2**. For each of the different types, e.g. pressure sensors, different functional principles and different technologies may be used to realise the device. This level of description is not shown.

The structure shown in **Figure 1-2** also affects the setup of the MEMS sensors knowledge matrix. The matrix for MEMS sensors is based on the structure of the knowledge matrix for semiconductor components, but adapted to the needs for MEMS sensors. While the classification into wafer related and package/assembly related items works to quite some extent for the issues in the standard semiconductor knowledge matrix (although even for this purpose the approach is debatable), a different way of classification was chosen for MEMS, which is shown in **Table 4-1** together with an example. Corresponding to the structure shown in **Figure 1-2**, the device under consideration is defined by nested categories. The classification as a pressure sensor is not detailed enough. As a further characteristic the physical principle by which the device functions is added. As the target is to look at failure mechanisms, information on the MEMS sensors element itself should be given.

MEMS Category	MEMS Product	MEMS Product Physical Principle	MEMS Elements
Inertial without contacts	pressure sensor	piezoresistive	thin membrane

Table 4-1: Classification of MEMS devices in the knowledge matrix

As argued before, no attempt was made to cover the full range of the device types shown in **Figure 1-2**. The intention of the knowledge matrix is rather to give an example of how such a matrix could be set up in a company, which wants to use this tool for Robustness Validation purposes. The question of the effectiveness of such a tool remains to be answered by each company separately.

The knowledge matrix can be found in the **Annex A2**

5. Accelerated Testing

In most cases, lifetime requirements are beyond what is acceptable as test time. This implies that the lifetime has to be compressed. Accelerated testing means exposing the product to stress conditions that induce failures in shorter time than use conditions without changing the failure mechanism. It is beyond the scope of the present document to give a detailed description of accelerated testing.

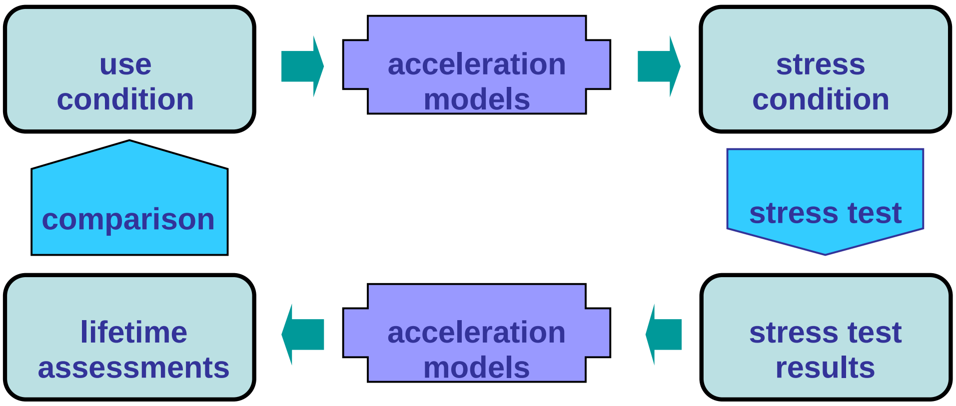


Figure 5-1: Idealised flow of accelerated testing and the role of acceleration models.

Figure 5-1 shows an (admittedly strongly) idealised flow of accelerated reliability testing. In order to convert use conditions to stress conditions and to convert stress test results backwards to lifetimes under use conditions, acceleration models are used. Among these acceleration models, the Arrhenius equation is the most widely known and used:

$$AF(T_{use}, T_{stress}) = \exp\left[\frac{E_a}{k}\left(\frac{1}{T_{use}} - \frac{1}{T_{stress}}\right)\right]$$

Here, AF is the acceleration factor, E_a the activation energy, k Boltzmann's constant and T the absolute temperature. Other examples of acceleration models are Peck's model for humidity stressing or the Coffin-Manson model for thermo-mechanical stressing.

It can hardly be overemphasised that the models require judicious usage. As lifetime assessment has to use extrapolation from accelerated test conditions to use conditions, blindly applying a model and/or parameter values for e.g. activation energies can lead to predictions that are wrong by orders of magnitude.

The prerequisite for accelerated testing is, quite obviously, that the test can be accelerated with respect to use conditions. There are several reasons, why this may not be the case, among them

- limitation by physics
- limitation by competing failure mechanisms
- limitation by design.

A closer look at the common stress tests that are used for product qualification reveals that not all of these tests aim at determining the lifetime of a product i.e. are intended to look at the wearout of the system/material. There are tests that target at determination of the strength of the system by applying some overload condition. Other tests are neither suited for lifetime determination nor for overload, they more or less mimic application conditions. In general, the tests may be classified into four categories, as given in **Table 5-1**.

A common issue is fast detection of weaknesses of a product/technology. This purpose is distinctly different from determining lifetime data and acceleration models and justified in its own right. Detecting weaknesses and gaining information on the way products fail is an important task, especially in the development phase. The setup of tests has to be tailored to this task and needs not coincide with standard qualification stress test conditions.

Determination of lifetimes and acceleration models/parameters requires extensive testing and failure analysis to verify that the intended failure mechanism is really addressed.

In general, Robustness Validation requires that tests be examined with respect to their suitability for addressing a specific failure mechanism, taking into consideration the application requirements. Test conditions and sample sizes have to be tailored to the problem in hand.

Category	Purpose	Abbr.
Wear out test	Tests to determine the lifetime of a system under repeated loading conditions below the strength of the materials	W
Overload tests	Tests to determine the destruction limit of the system under a specific load condition	O
Characterisation	Tests to determine the systematic, time zero behaviour of the system subject to parameter variation (e.g. temperature dependence of output signal)	C
Application tests	Tests to verify the capability of the system under specific application conditions	A

Table 5-1: Categories for qualification tests

An overview of stress tests is given in **Annex A3**. It lists the qualification tests used for MEMS sensors required in the AEC Q100 [2] and the ZVEI paper “Pressure Sensor Qualification beyond AEC Q100 – a Best Practice Guideline” [3]. It can be seen that a substantial part of the stress tests, especially those dedicated to MEMS sensors, are not real lifetime, i.e. wearout, tests, or they serve that purpose only under some restricted conditions. It can further be observed that no acceleration model is available for most of the sensor-specific wearout tests.

In the absence of accelerated tests, a valid and viable approach is to test to a certain margin of strength, which is a usual practice in mechanical engineering. For example, if a pressure sensor is specified up to a certain pressure P_{max}, it has to withstand a test up to a pressure of $k*P_{max}$, where k is a factor for the safety margin. Repeating that test for a number of times and inspection of the device for potential damage gives some information on the usability of the device.

A product may not be the most suitable means to investigate a specific failure mechanism. Dedicated test structures should be considered, because they can be analysed more easily and allow better modelling. Thus, test structures are often indispensable for understanding a certain failure mechanism and improving the technology/product.

Annex A3 illustrates that knowledge of tests used for MEMS sensors and their connection to the products and their materials is much less advanced than knowledge of the tests used for integrated circuits. One reason certainly is the comparably low market share of MEMS sensors, another reason is the wide variability. In conclusion, much work is needed in this field in the future to provide the base for better approaches.

6. Summary and Outlook

With this appendix to the ZVEI Handbook for Robustness Validation, basics for robustness validation for MEMS sensors have been elaborated.

Further activities already ongoing at ZVEI workgroups concern the definition of deliverables between suppliers and customers regarding Robustness Validation requirements of products.

We would also like to draw the reader's attention to the already available ZVEI "Handbook for Robustness Validation of Automotive Electric/Electronic Modules" [5].

Updates concerning Robustness Validation activities can also be found on the ZVEI Robustness Validation website under: http://www.zvei.org/index.php?id=342 (Press „Robustness Validation" button in the list on the left side)

Comments and questions can be sent to ZVEI, Dr. Baumann or placed on the above mentioned website

7. References and Additional Readings

[1] ZVEI Brochure "Handbook for Robustness Validation of Semiconductors Devices in Automotive Applications", April 2007

[2] AEC - Q100 - Rev-G, May 14, 2007 - Failure Mechanism Based Stress Test Qualification for Integrated Circuits.

[3] ZVEI Brochure "Pressure Sensor Qualification beyond AEC Q100 – a Best Practice Guideline", November 2008

[4] ZVEI Homepage "Robustness Validation", http://www.zvei.org/robustnessvalidation

[5] ZVEI Brochure "Handbook for Robustness Validation of Automotive Electric/Electronic Modules", June 2008

Additional readings can be found in the ZVEI Handbook [1] .

8. Participants of the Working Group

Participant	Company
Baumann, Sven	ZVEI
Bender, Karl	Robert Bosch GmbH
Chmiel, Gerhard	ELMOS Semiconductor AG
Corten, Wim	Melexis GmbH
Jäger, Barbara	Infineon Technologies AG
Jost, Franz	Sensitec GmbH
Kanert, Werner	Infineon Technologies AG
Mischke, Helge	First Sensor Technology GmbH
Oeser, Helm-Henning	First Sensor Technology GmbH
Pekkola, Jan	VTI Technologies Oy
Scherb, Gerhard	Continental Automotive GmbH
Wagner, Dieter	Continental Automotive GmbH
Zentgraf, Berthold	JUMO GmbH
Ziermann, René	Endress+Hauser GmbH+Co. KG

Annex

A.1 Mission Profile Examples

The Mission Profiles in this chapter are simplified ‘typical’ loads for different mounting locations.
Note: these profiles are estimations which represent typical operational profiles of different drivers in a passenger car and have to be validated.

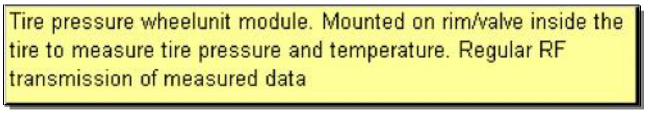
However, for several kinds of loads, such as vibration, corrosion and water intrusion, parameters for lab tests rather than typical values are given:
If the translation of field load to test load is too difficult or the acceleration between field and test conditions (e.g. for some chemical loads) is unknown today, the use of proven standards is encouraged.

A.1.1 Mission Profile Example: MEMS for Tire Pressure Monitoring System Wheel Unit (TPMS-WU)

This example deals with a Standard Sensor that is the sensing part of a TPMS-WU. It connects via RF to a receiving EEM in the vehicle. This is only an example which is not necessarily accurate or complete.

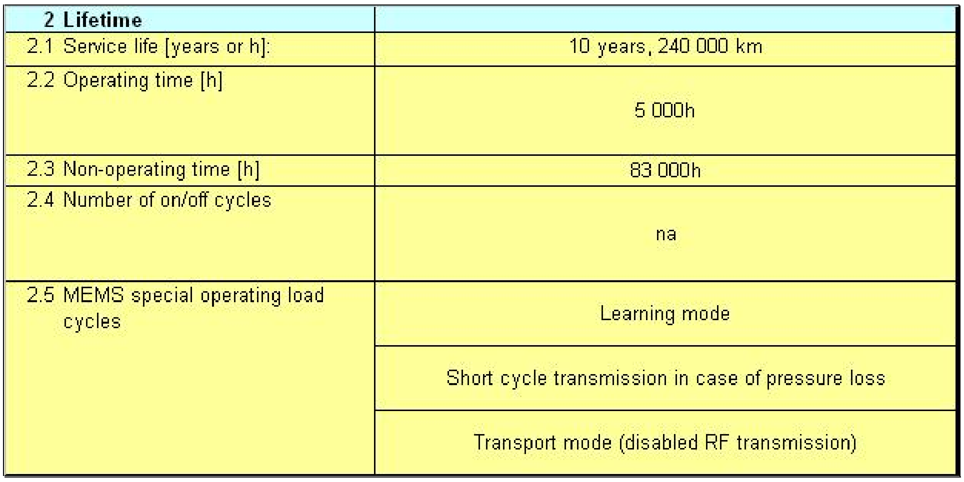
The significant climatic, electrical, mechanical, and chemical influences which impact on the sensor during its service life are summarized in the following application profile.

A.1.1.1 Mounting location of the sensor



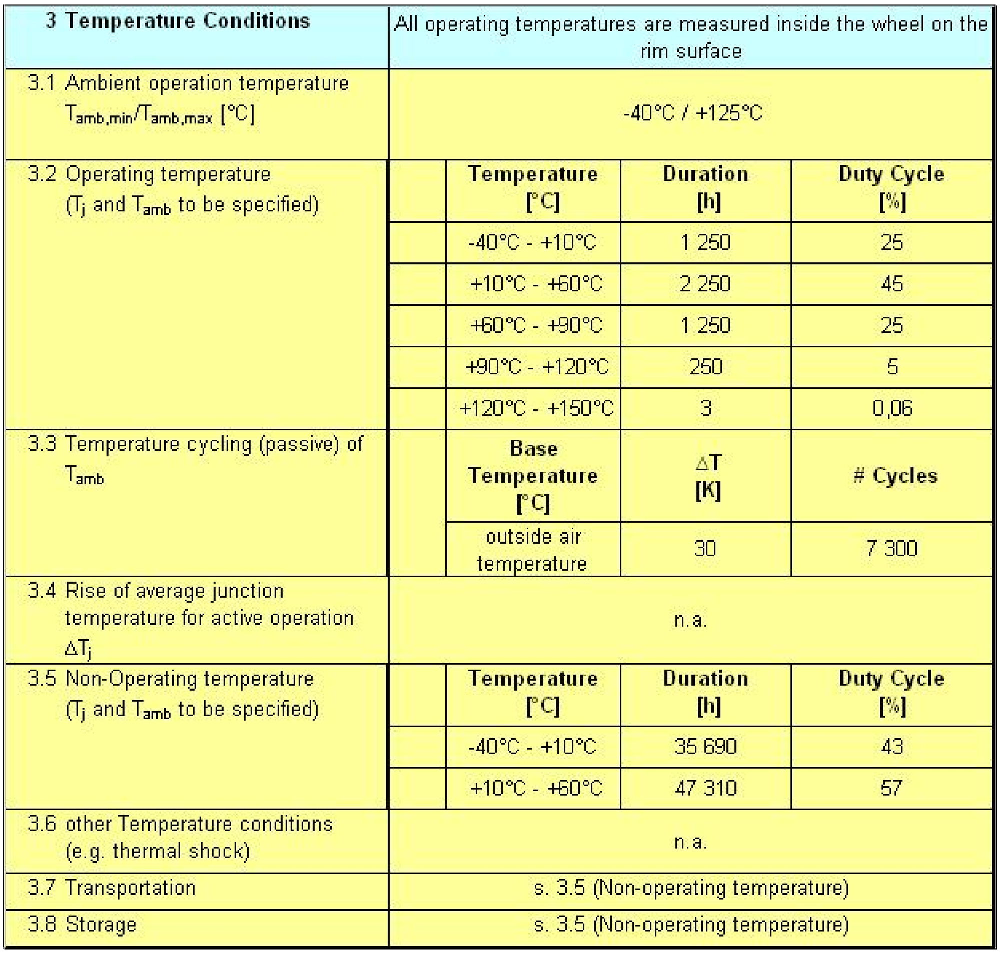
Tire pressure wheelunit module. Mounted on rim/valve inside the tire to measure tire pressure and temperature. Regular RF transmission of measured data

A.1.1.2 TPMS-WU Service life



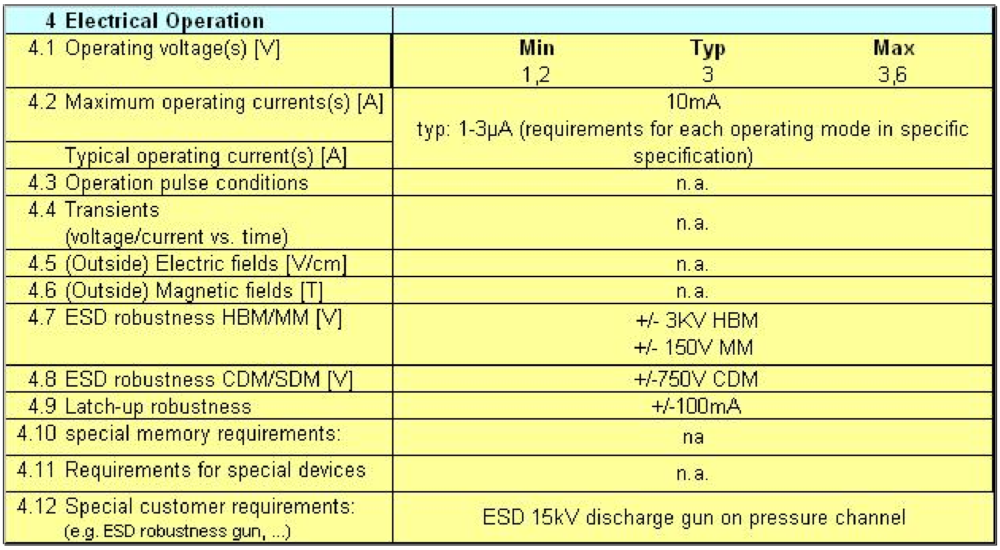
2 Lifetime	
2.1 Service life [years or h]:	10 years, 240 000 km
2.2 Operating time [h]	5 000h
2.3 Non-operating time [h]	83 000h
2.4 Number of on/off cycles	na
2.5 MEMS special operating load cycles	Learning mode
	Short cycle transmission in case of pressure loss
	Transport mode (disabled RF transmission)

A.1.1.3 Temperature conditions



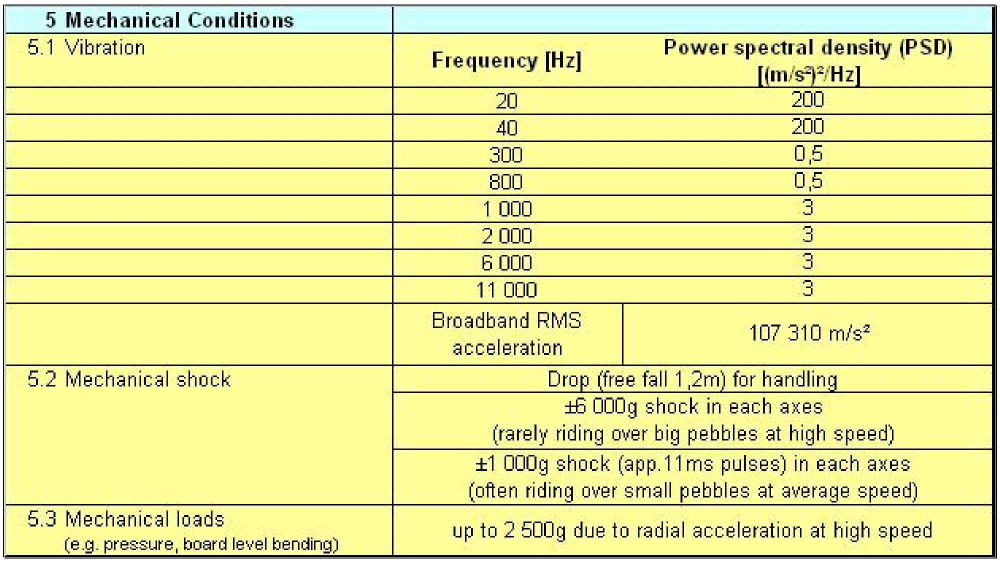
3 Temperature Conditions	All operating temperatures are measured inside the wheel on the rim surface			
3.1 Ambient operation temperature $T_{amb,min}/T_{amb,max}$ [°C]	-40°C / +125°C			
3.2 Operating temperature (T_j and T_{amb} to be specified)		**Temperature [°C]**	**Duration [h]**	**Duty Cycle [%]**
		-40°C - +10°C	1 250	25
		+10°C - +60°C	2 250	45
		+60°C - +90°C	1 250	25
		+90°C - +120°C	250	5
		+120°C - +150°C	3	0,06
3.3 Temperature cycling (passive) of T_{amb}		**Base Temperature [°C]**	**ΔT [K]**	**# Cycles**
		outside air temperature	30	7 300
3.4 Rise of average junction temperature for active operation ΔT_j	n.a.			
3.5 Non-Operating temperature (T_j and T_{amb} to be specified)		**Temperature [°C]**	**Duration [h]**	**Duty Cycle [%]**
		-40°C - +10°C	35 690	43
		+10°C - +60°C	47 310	57
3.6 other Temperature conditions (e.g. thermal shock)	n.a.			
3.7 Transportation	s. 3.5 (Non-operating temperature)			
3.8 Storage	s. 3.5 (Non-operating temperature)			

A.1.1.4 Electrical conditions, ESD



4 Electrical Operation			
4.1 Operating voltage(s) [V]	**Min** 1,2	**Typ** 3	**Max** 3,6
4.2 Maximum operating currents(s) [A]	10mA		
Typical operating current(s) [A]	typ: 1-3µA (requirements for each operating mode in specific specification)		
4.3 Operation pulse conditions	n.a.		
4.4 Transients (voltage/current vs. time)	n.a.		
4.5 (Outside) Electric fields [V/cm]	n.a.		
4.6 (Outside) Magnetic fields [T]	n.a.		
4.7 ESD robustness HBM/MM [V]	+/- 3KV HBM +/- 150V MM		
4.8 ESD robustness CDM/SDM [V]	+/-750V CDM		
4.9 Latch-up robustness	+/-100mA		
4.10 special memory requirements:	na		
4.11 Requirements for special devices	n.a.		
4.12 Special customer requirements: (e.g. ESD robustness gun, ...)	ESD 15kV discharge gun on pressure channel		

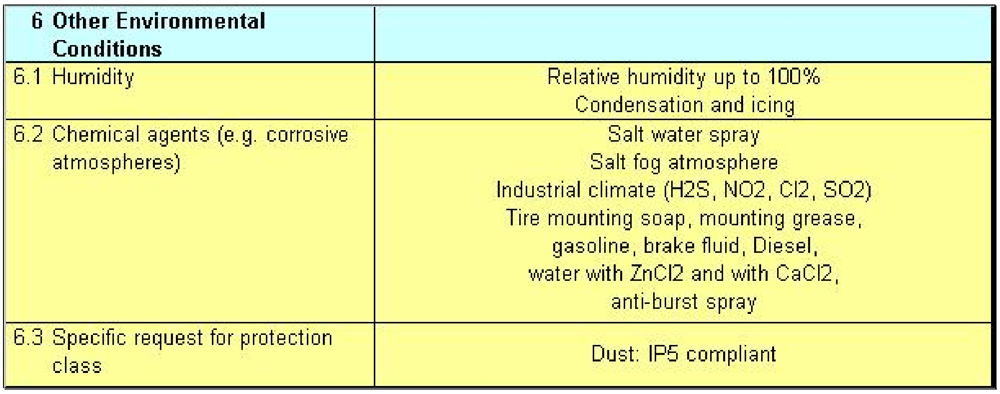
A.1.1.5 Mechanical conditions



5 Mechanical Conditions		
5.1 Vibration	**Frequency [Hz]**	**Power spectral density (PSD) [(m/s^2)^2/Hz]**
	20	200
	40	200
	300	0,5
	800	0,5
	1 000	3
	2 000	3
	6 000	3
	11 000	3
	Broadband RMS acceleration	107 310 m/s^2
5.2 Mechanical shock	Drop (free fall 1,2m) for handling	
	±6 000g shock in each axes (rarely riding over big pebbles at high speed)	
	±1 000g shock (app.11ms pulses) in each axes (often riding over small pebbles at average speed)	
5.3 Mechanical loads (e.g. pressure, board level bending)	up to 2 500g due to radial acceleration at high speed	

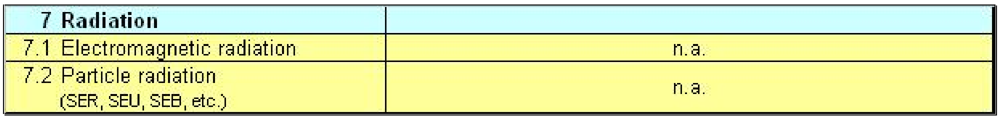
Remarks: Accelerated test condition, worst case field scenario envelope curve

A.1.1.6 Other environmental conditions



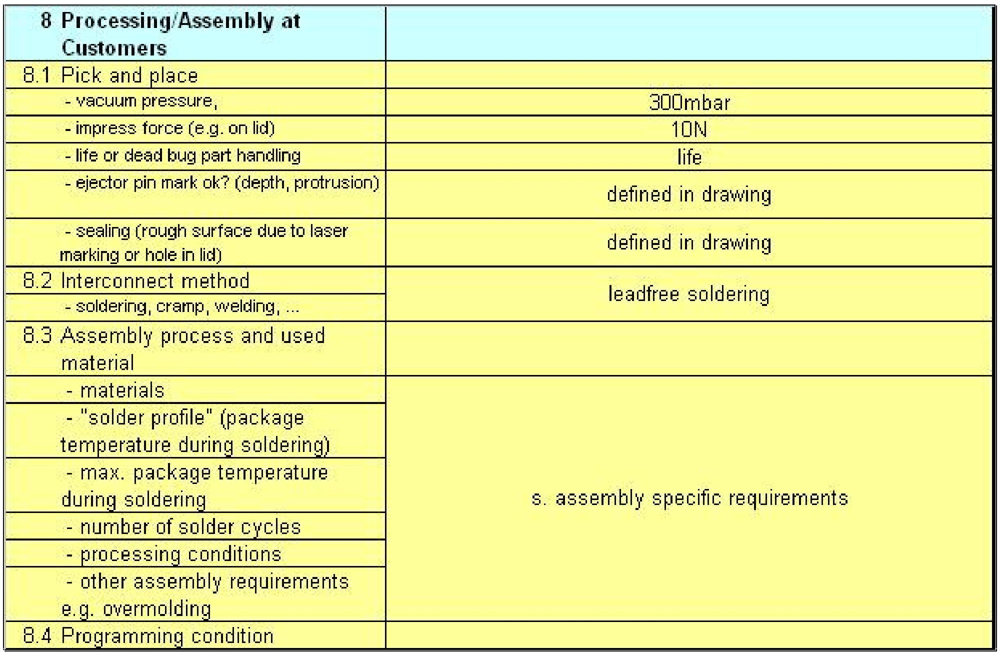
6 Other Environmental Conditions	
6.1 Humidity	Relative humidity up to 100% Condensation and icing
6.2 Chemical agents (e.g. corrosive atmospheres)	Salt water spray Salt fog atmosphere Industrial climate (H2S, NO2, Cl2, SO2) Tire mounting soap, mounting grease, gasoline, brake fluid, Diesel, water with ZnCl2 and with CaCl2, anti-burst spray
6.3 Specific request for protection class	Dust: IP5 compliant

A.1.1.7 Radiation



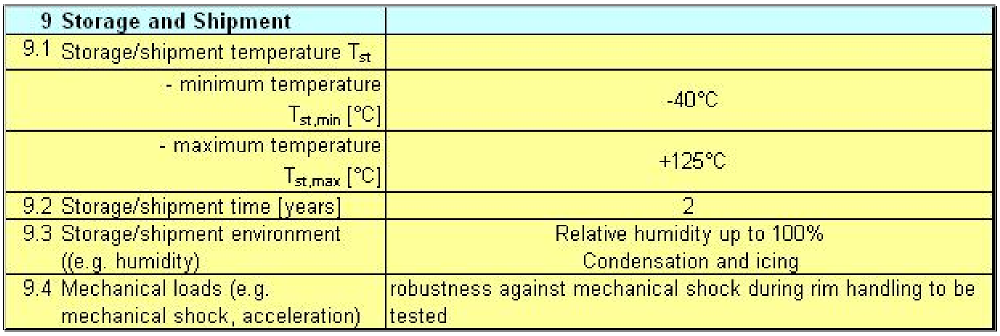
7 Radiation	
7.1 Electromagnetic radiation	n.a.
7.2 Particle radiation (SER, SEU, SEB, etc.)	n.a.

A.1.1.8 Special conditions at customer during processing/assembly



8 Processing/Assembly at Customers	
8.1 Pick and place	
- vacuum pressure,	300mbar
- impress force (e.g. on lid)	10N
- life or dead bug part handling	life
- ejector pin mark ok? (depth, protrusion)	defined in drawing
- sealing (rough surface due to laser marking or hole in lid)	defined in drawing
8.2 Interconnect method	leadfree soldering
- soldering, cramp, welding, ...	
8.3 Assembly process and used material	
- materials	s. assembly specific requirements
- "solder profile" (package temperature during soldering)	
- max. package temperature during soldering	
- number of solder cycles	
- processing conditions	
- other assembly requirements e.g. overmolding	
8.4 Programming condition	

A.1.1.9 Storage and shipment



9 Storage and Shipment	
9.1 Storage/shipment temperature T_{st}	
- minimum temperature $T_{st,min}$ [°C]	-40°C
- maximum temperature $T_{st,max}$ [°C]	+125°C
9.2 Storage/shipment time [years]	2
9.3 Storage/shipment environment ((e.g. humidity)	Relative humidity up to 100% Condensation and icing
9.4 Mechanical loads (e.g. mechanical shock, acceleration)	robustness against mechanical shock during rim handling to be tested

A.1.1.10 Relevant functional loads of TPMS wheelunit sensor

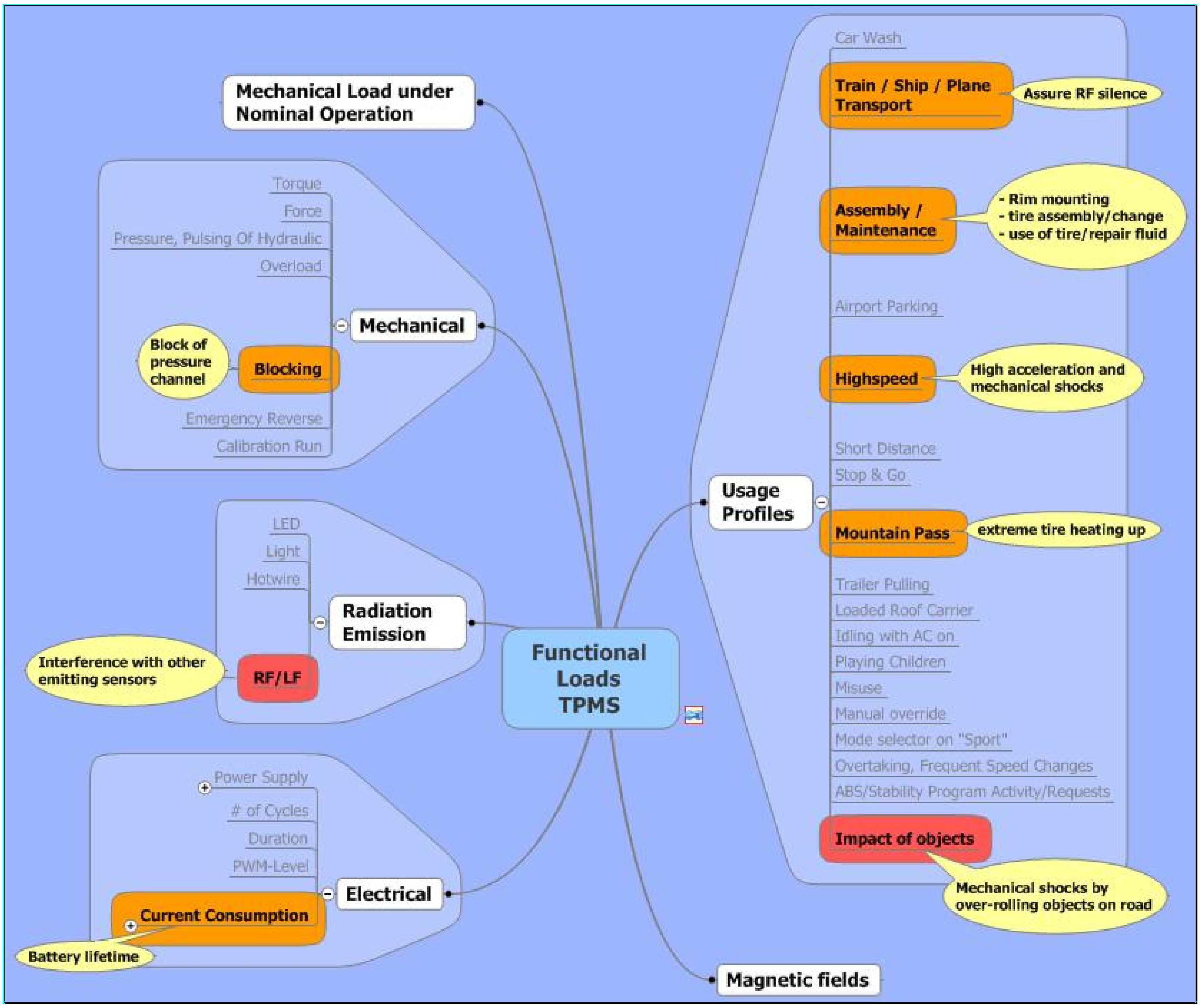


Figure A1-1: Tree analysis functional loads TPMS wheelunit

Note, that this assessment indicates relevant functional loads for a virtual product. Please check the relevance in detail for your design and application.

- Orange: relevant load
- Red: additional relevant load
- Grey: load not relevant
- Bubble: Comment

A1.2 Relevant functional loads of front airbagsensor

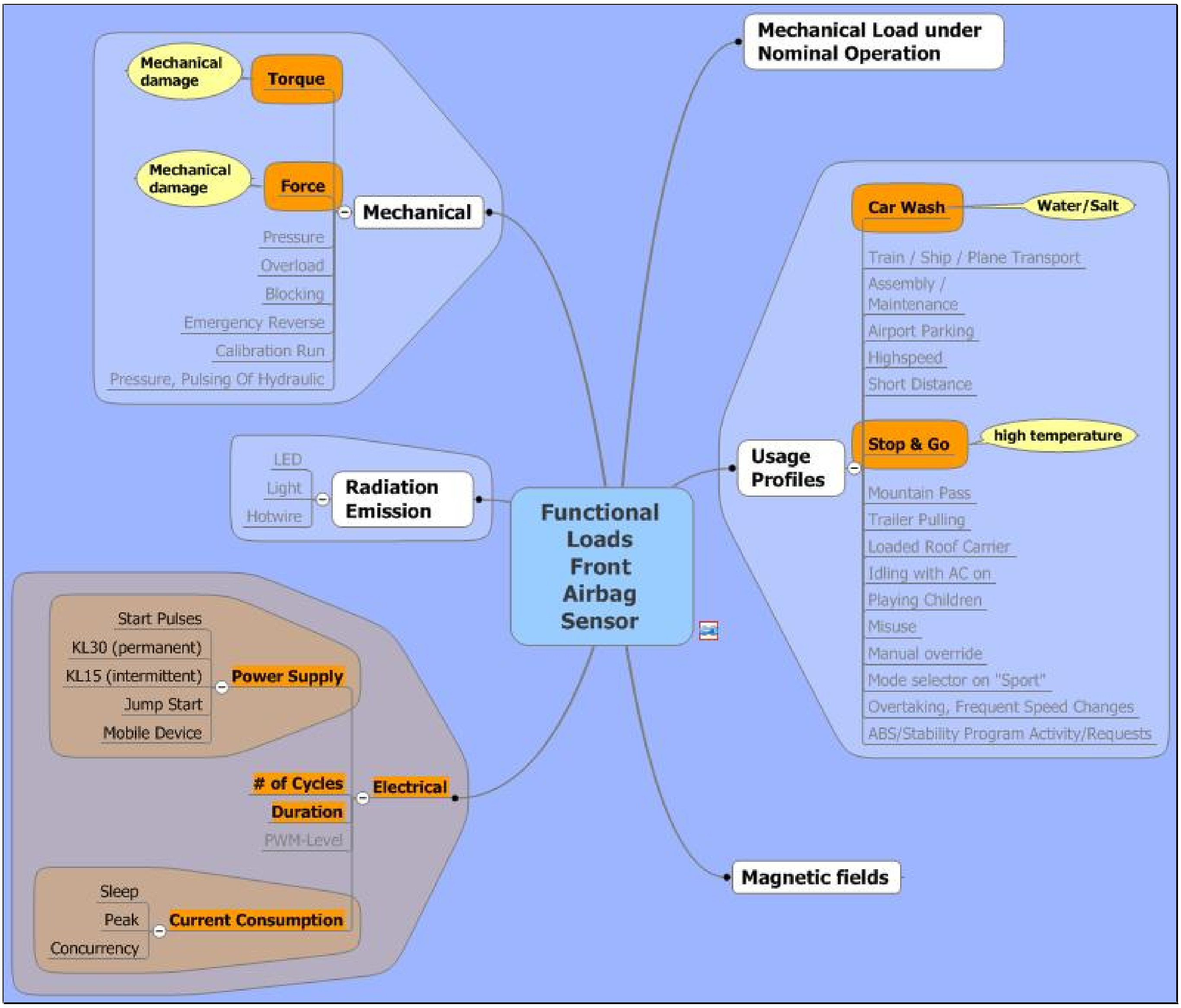


Figure A1-2: Tree analysis functional loads front airbagsensor

Note, that this assessment indicates relevant functional loads for a virtual product. Please check the relevance in detail for your design and application.

- Orange: relevant load
- Red: additional relevant load
- Grey: load not relevant
- Bubble: Comment

A.1.3 Relevant functional loads wheelspeed sensor

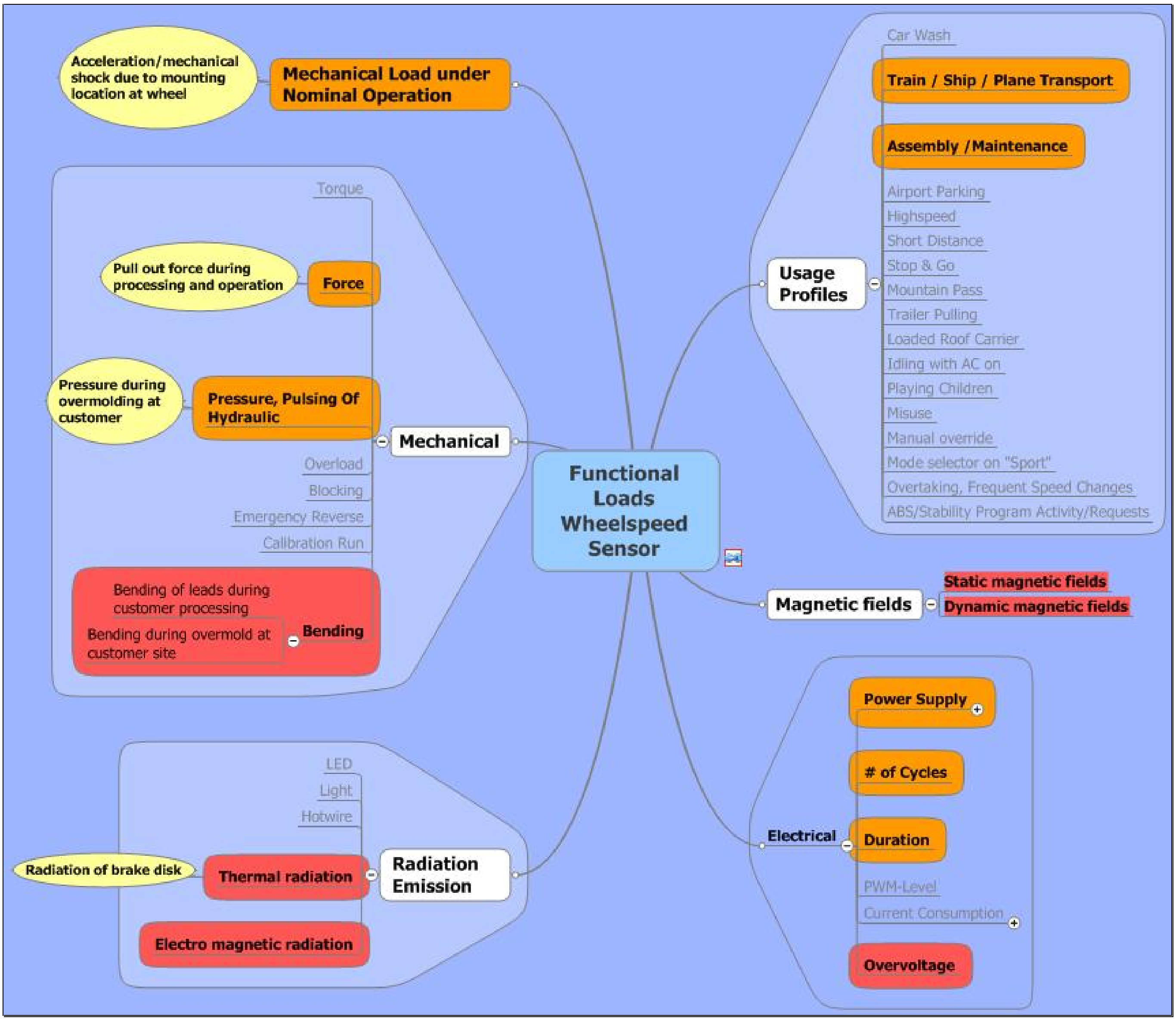


Figure A1-3: Tree analysis relevant functional loads for wheelspeed sensor

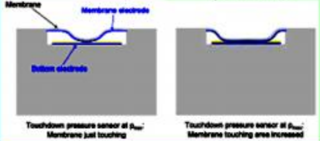
Note, that this assessment indicates relevant functional loads for a virtual product. Please check the relevance in detail for your design and application.

- Orange: relevant load
- Red: additional relevant load
- Grey: load not relevant
- Bubble: Comment

A.1.4 Mission Profile Template

You will find a mission profile Template with the above mentioned TPMS example and additional hints in the attached file "Mission Profile Template_TPMS example and hints.xls".

A.2 Knowledge Matrix Table

MEMS Category	MEMS Product	MEMS Product Physical Principle	MEMS Elements	Failure cause	Failure mechanism	Failure mode	Material	Detection/ test	Characteriz.	Application	Design test struct	Design for Testability (dft), Design for Reliability (dfr)	Stress method	Acceleration model	Ref (test method)	Comments
Inertial without contacts	pressure sensor	piezoresistive	Thin membrane	mechanical stress	overload fracture	functional	Silicon	burst pressure test	electrical/ monitoring pressure supply	pressure scaling	product/ test membranes		rising stress load (+ temperature)			
Inertial without contacts	pressure sensor		Thin membrane	design/process	stiction	functional (can be intermittent/reversible)	silicon	pressure ramp test, high pressure test	no response on external stimulus	pressure measurement	product					
Inertial without contacts	acceleration sensor		Moveable mass	design/process	stiction	functional (can be intermittent/reversible)	silicon	shock testing	no response on external stimulus	acceleration measurement	product					
Inertial without contacts	acceleration sensor		Moveable mass	design/process	structure break	functional	silicon	shock testing; constant acclerartion	no response on external stimulus	acceleration measurement	product/test structures					
Inertial without contacts	acceleration sensor		Moveable mass	process/design	blocking of movement by particles	functional (can be intermittent/reversible)	silicon	shock testing	no response on external stimulus; reduced measurement range	acceleration measurement			repeated shock, if particles are generated by wear			
	many		sealed cavity		hermeticity failed	change of characteristics	silicon and sealing depending on process used	resonance frequency/q-factor	distorted response on external stimulus	many	product/test structure	include resonant structure	HAST, pressure cooker, THB			
CAVEAT: Some content on this sheet may be protected by 3rd party IP and/or covered by patents.																
	pressure sensor		Thin membrane	design (dimension, material)/process	stiction	functional (can be intermittent/reversible) (stuck at high)	silicon	pressure ramp test, high pressure test	no response on external stimulus	pressure measurement	product					stiction is a general topic to be considered in design phase
	pressure sensor		touch down sensor (capacitive sensor)					contact of surfaces given by design design review pressure ramp up/ramp down (slow), check for hysteresis/jumps high pressure test with dwell time	no consistent reaction on external stimulus (jumps, hysteresis)		on product level	**dfr**:minimize contact area that is in direct contact relative to total surface area; avoid perfectly flat contact surfaces	design related: slow pressure ramp up/ramp down; high pressure test with dwell time degradation related: fast high pressure cycle test, followed by design related stress test	not accelarated wear out model?	none	
	pressure sensor		non contact sensor					design review if contact possible before destruction of membrane test for pressure to make contact max pressure test pressure cycle test	no consistent reaction on external stimulus (jumps, hysteresis)		on product level	**dft:** enable diagnosis for contact (electrical contact) **dfr:** stuctures to minmize contact area; avoid perfectly flat contact surfaces	design related: slow pressure ramp up/ramp down; high pressure test with dwell time degradation related: fast high pressure cycle test, followed by design related stress test	not accelarated wear out model?	none	
	pressure sensor	piezoresistive	Si-/glass wafer bond	particle contamination	delamination Si-Glass	reduced burst force / leakage	Silicon -glass	Burst pressure test/ test with Chevron structures	optical inspection	pressure measurement	product/ test structure	dft: suitable Chevron structure dfr: check critical particle size		no	none	
	pressure sensor	piezoresistive	Si-/glass wafer bond	high surface roughness	delamination Si-Glass	reduced burst force / leakage	Silicon -glass	Burst pressure test/ test with Chevron structures	optical inspection	pressure measurement	product/ test structure	dft: suitable Chevron structure dfr: check of critical surface roughness		no	none	
	pressure sensor	piezoresistive	Si-/glass wafer bond	surface contamination/ cleaning procedure	delamination Si-Glass	reduced burst force / leakage	Silicon -glass	Burst pressure test/ test with Chevron structures	optical inspection	pressure measurement	product/ test structure	dft: suitable Chevron structure		no	none	
Inertial without contacts	gyroscopes															
Inertial without contacts	microphones															
Inertial with contacts	switches															
Inertial with contacts	micromirrors															
Inertial with contacts	pumps															
Non-inertial	chemical sensor															
Non-inertial	inkjet printhead															
Slding	gears															
Slding	motors															

A.3 Overview Stress Tests

Stress Test	Abbr.	Stressor	Classification[1]	Acceleration Model	Purpose of test/ Weak points addressed Failure mechanism
Preconditioning	PC	moisture + temperature	A	No acceleration, simulation of processing of device at tier1	Simulation of worst case conditions at soldering process
Temperature Humidity Bias	THB	T, H, V	W	Peck, Lawson, etc. (limited)	Passivation of surface, potential corrosion of metals and contacts, package sealing delamination, durability of passivation, stress corrosion cracking (glass)
Highly Accelerated Stress Test	HAST	T, H, V	W	Peck, Lawson, etc. (limited)	Passivation of surface, potential corrosion of metals and contacts (with bias activation)
Autoclave	AC	T, H	O	no	Passivation of surface, potential corrosion of metals and contacts, package sealing (highest accelerating effect)
Unbiased Highly Accelerated Stress Test	UHAST	T, H	W	Peck, Lawson, etc. (limited)	Passivation of surface, potential corrosion of metals and contacts, package sealing (high accelerating effect)
Temperature Cycling	TC	ΔT, T	W	Coffin-Manson and variants	Thermo-mechanical compatibility of different materials, material strength, creep
Power Temperature Cycling	PTC	V, I, ΔT	W	no	Thermal resistance, material fatigue creep
High Temperature Storage Life	HTSL	T	W	Arrhenius	Thermal resistance, aging
High Temperature Operating Life	HTOL	V, I, T	W	Eyring	Early failure rate, long term failure rate, long term stability,
Mechanical Shock	MS	mechanical stress	W/O	no	Mechanical stability, material fatigue, adhesion, stiction and overload fracture
Mechanical Shock (Bump test)	MS	mechanical stress	O	no	Mechanical stability, material fatigue, adhesion, stiction and overload fracture

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[1] see Table 5.1

Stress Test	**Abbr.**	**Stressor**	**Classification**[1]	**Acceleration Model**	**Purpose of test/** **Weak points addressed** **Failure mechanism**
Variable Frequency Vibration	VFV	mechanical stress	W/A/O	Steinberg	Mechanical stability, material fatigue, environmental requirement fracture due to critical resonances
Constant Acceleration	CA	mechanical stress	W/O/A depending on application and failure mechanism	no	Mechanical stability, material fatigue, environmental requirement
Package Drop	DROP	mechanical stress	W/O/A depending on application and failure mechanism	no	Mechanical stability, material break, package ability to product preservation, adhesion, stiction and overload fracture
Gross/Fine Leak	GFL	pressure	O	no	Sealing, leakage rate
Lid Torque	LT	mechanical stress	C	no	Mechanical stability
Die Shear	DS	mechanical stress	C	no	Die attach strength
Internal Water Vapour	IWV	-	C	no	Package sealing
Burst Pressure	BP	pressure	O/C	no	Material strength, material bonding, design, overload fracture
Pulsed Pressure Cycling	PPC	pressure	W	no	Material strength, material fatigue
Pulsed Pressure Temperature Cycling	PPTC	pressure + ΔT	W	no	Material strength, material fatigue, parameter stability
Muliple Pulsed Pressure	MPP	pressure	W	no	Material strength, material fatigue, design
Low Air Pressure Storage	LAPS	pressure	A	no	Mechanical stability, environmental requirement, simulation of storage process

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[1] see Table 5.1

Stress Test	Abbr.	Stressor	Classification[1]	Acceleration Model	Purpose of test/ Weak points addressed Failure mechanism
Overpressure	OP	pressure	C	no	Material strength, parameter hysteresis, design, overload fracture, creep
Chemical Resistance	CR	chemical agents	W/C/A	no	Resistance to chemical loads, corrosion
Salt Spray	SSP	chemical agents	A	no	Resistance to environmental loads, corrosion
Condensating Humidity with Sulphur	CHS	chemical agents	A	no	Resistance to chemical loads, corrosion

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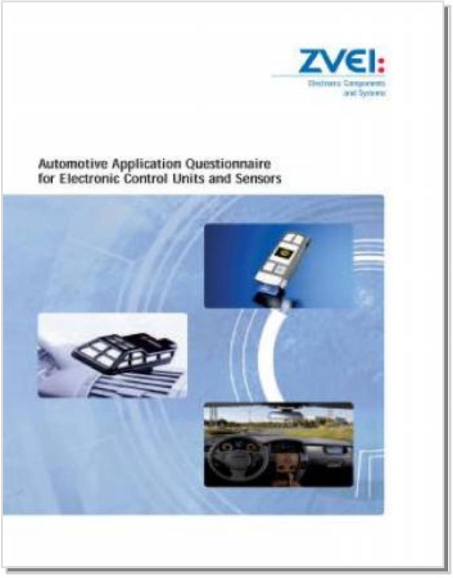
1) see Table 5.1

Further publications of Electronic Components and Systems division

ZVEI:

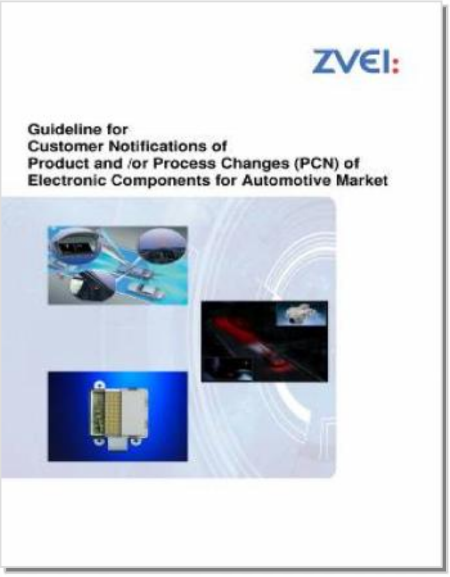
"Pb-frei": Whiskerarme Sn-Oberflächen, Verarbeitbarkeit, Löten und Lötwärmebeständigkeit für Automotive Anwendungen

Februar 2007



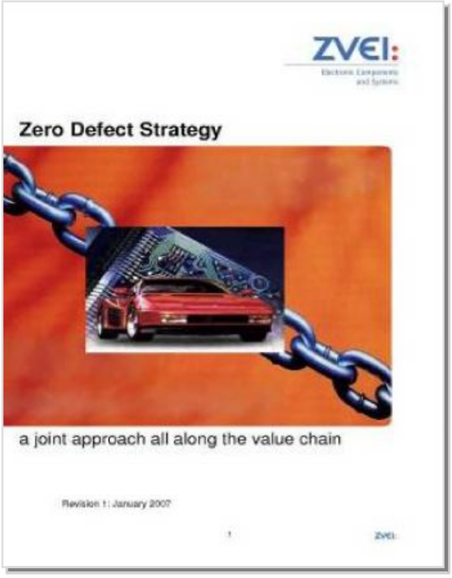
ZVEI:

Automotive Application Questionnaire for Electronic Control Units and Sensors



ZVEI:

Guideline for
Customer Notifications of
Product and /or Process Changes (PCN) of
Electronic Components for Automotive Market



ZVEI:

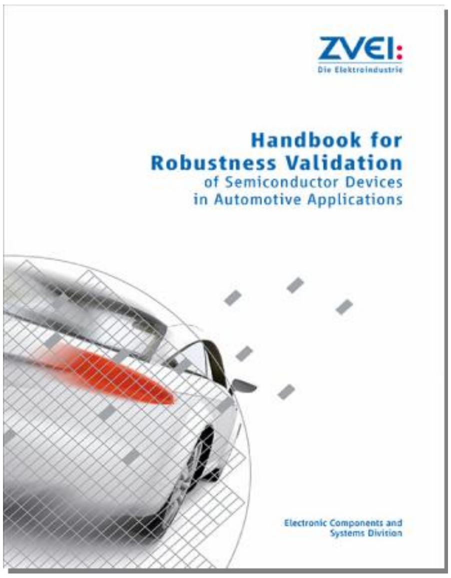
Zero Defect Strategy

a joint approach all along the value chain

Revision 1: January 2007

1

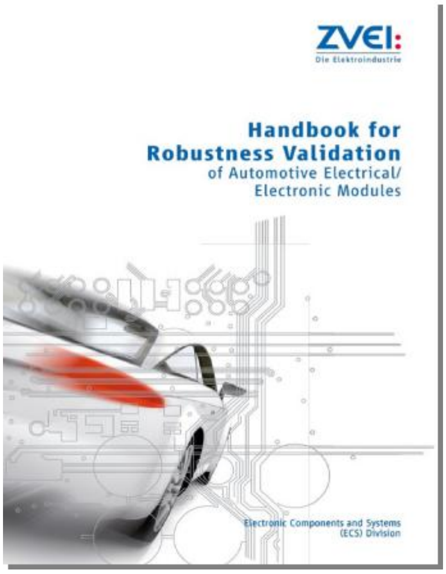
ZVEI



ZVEI:
Die Elektroindustrie

Handbook for
Robustness Validation
of Semiconductor Devices
in Automotive Applications

Electronic Components and
Systems Division



ZVEI:
Die Elektroindustrie

Handbook for
Robustness Validation
of Automotive Electrical/
Electronic Modules

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