Extended lifetime qualification concepts for automotive semiconductor components

T. Lehndorff [1], U. Abelein [2], A. Alsioufy [1], A. Hirler [1], T. Sulima [1], S. Simon [3], H. Lochner [3], W. Hansch [1]

1. Universität der Bundeswehr, EIT-2 Institute of Physics, Werner-Heisenberg-Weg 39,
85577 Neubiberg, Germany

2. Infineon Technologies AG, Am Campeon 1-15, 85579 Neubiberg, Germany

3. Audi AG, I/GQ-F5, 85045 Ingolstadt, Germany

Abstract—**Current automotive megatrends electro mobility, digitalization and autonomous driving lead to more demanding reliability requirements for automotive semiconductors. The most significant change applies to the operating time, which increases at least by a factor four.**

In this work, a typical new mission profile is used to highlight that the established qualification procedure using standardized stress test conditions, the AEC-Q100, is not sufficient to proof fulfillment of these new life-cycle requirements.

Different solutions to extend the existing standard to cover the new requirements are discussed. Those are extended test conditions, Robustness Validation and standardized extended lifetime requirements (SELR).

Extended test conditions will preserve the transparency of the existing standard. But they bear the risk that significant efforts are necessary to meet the standard, which does not necessarily reflect the demanded reliability requirements.

Robustness Validation results in an application specific reliability assessment. This detailed and highly flexible method causes high efforts to obtain the relevant reliability data on supplier side and to assess it on customer side.

The proposed new concept of SELR combines the broad usability of standardized methods with the flexibility of Robustness Validation. It is therefore a promising method to cover future challenges in the validation and qualification of future automotive semiconductor technologies.

Index Terms—**Automotive, Autonomous Vehicles, Connectivity, Digitalization, Electric Vehicles, Mission Profile, Robustness Validation, Standardized Extended Lifetime Requirements, SELR, Semiconductor Reliability**

I. INTRODUCTION

The automotive industry is currently facing significant changes. Global megatrends are now present within industries that once lagged technology trends. Strict emission regulations boost the rise of electro mobility. Digitalization of our everyday life has reached the car, making connectivity one of the trending topics today. And with the increasing use of advanced driver-assistance systems the autonomous driving vehicle is within reach.

These megatrends cause new challenges for automotive semiconductor devices and their reliability. The industry demands leading-edge semiconductor technologies while at the same time driving an increased operating time requirement.

The amount of semiconductor devices in one car has risen significantly in the last years to currently more than 7,000 components [1]. As a result, the reliability of the components has a significant impact on the reliability of the vehicle. Therefore, the semiconductor reliability and today's standard method of qualification are in focus of this work.

This paper describes how longer operating times emerge from the megatrends of the industry. In a next step, it is shown that the current industry wide accepted qualification standard for automotive semiconductor ICs, the AEC-Q100 [2], has difficulties covering the emerging longer operation times.

Finally, three different solutions are presented to extend the existing standard. These solutions are discussed and compared to estimate which is the most promising one.

II. THE LIMITS OF THE CURRENT STANDARD QUALIFICATION

In the era of the combustion engine, the maximum lifetime requirements of the mechanical components and of most electrical and electronic components have been connected to the operating time of the engine.

The internal company standard VW 80000 [3] requires 8,000 h of driving operation, a lifetime of 15 years and a mileage of 300,000 km for a vehicle. Similar requirements are used by several other vehicle manufacturers.

Up to now, many electronic control units (ECU) in combustion engine vehicles are only operating if the ignition is on. In the following, the lifetime requirements that emerge from these use-cases are called standard lifetime requirements.

The reliability requirements are changing in the context of electro mobility, digitalization and autonomous driving.

Electro mobility leads to additional operating states beside driving and parking. Examples are on-grid parking, vehicle preconditioning and charging. As a consequence of these new operating states, the operating times are rising.

Digitalization is connected to topics like car-to-x communication, swarm intelligence, over-the-air software updates and a permanent accessibility of the car for any request by the customer. Consequently, the vehicle might be "always on" resulting in operating time up to 24 hours 7 days per week.

Autonomous driving does not necessarily lead to increasing operating times since the use-model of the car is not affected at first. The main change in requirements is the need of high-performance computing power and therefore of leading-edge semiconductors. A close look reveals that the driverless operation enables a change in the use-model like mobility on demand or car sharing. These use-models result in higher driving operation times and therefore increasing operating times for several ECUs.

These examples point out that, emerging from the megatrends within in the automotive industry, the biggest impact on automotive electronics reliability is an increase of operating time and extended lifetime requirements.

Standard based product qualification is a commonly used approach to prove that an ECU or semiconductor device is fulfilling certain application lifetime requirements. This provides a high grade of transparency for the customer by having standardized test conditions and therefore comparability. Additionally, a widely accepted standard enables the device manufacturer to develop a product without specific customer input on reliability requirements in an early stage but still meeting the demands of the market.

The product qualification is not identical with the technology qualification. The technology qualification gives a deeper insight into the capabilities of a technology itself. The methods and results of a technology qualification are focusing on failure mechanisms their influence on the degradation of the base elements of the technology. The amount of details prevents a straight forward assessment of the resulting over all product reliability. The reason is that this is strongly influenced by the interaction of the intrinsic reliability of the technology and the design rules applied. On the other hand, the product qualification is meant to satisfy the needs of the communication with customers

A. Current standard qualification

For standard lifetime requirements with 8,000 h operating time, it can be shown that a semiconductor device is ready to be used in automotive applications if it passes the tests listed in the AEC-Q100 standard (published by the Automotive Electronics Council). But the AEC is aware that there are lifetime requirements that are not covered by the tests as specified. Therefore, the standard demands checking if the test conditions cover the requirements.

This standard defines product tests, meaning that the chip in package is tested. Therefore, not only silicon failure mechanisms are addressed, but also package related failures are activated. The standard defines test groups with different tests to address the different failure mechanism locations

The concept of this standard is to use stress tests with a zero fail pass condition to obtain an estimation whether the device is reliable on a certain level. The standard is based on the concept of accelerated testing. Instead of testing the device as long as it will be used in the application, tests are performed at an elevated stress level to reduce the test time. The idea is that test times, at elevated stress levels, represent the operating time at the operating condition.

Test conditions and test durations are well defined for each test.

The AEC-Q100 defines temperature grades where test conditions are directly linked to. The grade 0 is the most demanding temperature grade and specifies an ambient operating temperature range from -40 °C to 150 °C for the device. The temperature will be the stressor and the requirement which is discussed in this paper. Ambient temperature in this case means the temperature inside the ECU.

A test which is used as an accelerated lifetime simulation test is the high temperature operating life (HTOL). It triggers temperature and voltage driven failure mechanisms. The HTOL test conditions according to the standard are:

- Sample size: 3x77 devices from 3 production lots
- Test duration: 1,000 h
- Stress test temperature: T_{ambient} = 150 °C
- Stress test voltage (DC): $V_{\max}$ acc. datasheet [2].

The standard neither defines operating times, nor operating conditions for the component in the vehicle.

A close look at the sample size reveals a conflict with the common zero-defect strategy which is used in the automotive industry. This is not a real conflict, since the AEC-Q100 is a product qualification and not a technology qualification. For the sake of simplification this conflict is accepted.

The question arises to which degree this accelerated test covers the required 8,000 h of operating time. Since the devices are neither always on (DC-voltage), nor is the ambient temperature in real vehicle 150 °C for 1,000 h, it is necessary to correlate the test conditions with the real operating conditions.

A typical method to define lifetime requirements closely to real conditions are mission profiles. The temperature requirements are often represented by a spectrum with a time distribution instead of a minimum and a maximum temperature. Table I shows a typical example for a temperature spectrum. It is based on the Class 3 spectrum given in the ZVEI "Automotive Application Questionnaire for Electronic Control Units and Sensors" [4]. Since those are ambient temperatures outside the ECU, the spectrum was modified by additional +5 °C to include possible self-heating effects inside the ECU, which is the ambient temperature for the device (T_{ambient}). Since the maximum temperature exceeds 125 °C, which corresponds to grade 1, this spectrum would formally only be covered by AEC-Q100 grade 0 components.

TABLE I
8,000 H OPERATING TIME TEMPERATURE SPECTRUM BASED ON ZVEI "AUTOMOTIVE APPLICATION QUESTIONNAIRE FOR ELECTRONIC CONTROL UNITS AND SENSORS [4]

T_{ambient} [°C]	Operating time ($t_{\text{operating}}$) [h]
-35	480
28	1,600
81	5,200
125	640
130	80

Stress test conditions can be calculated from operating times of a mission profile by using an acceleration model developed from a physics-of-failure approach.

For temperature driven failure mechanisms that are e. g. based on diffusion effects, the Arrhenius equation is usually used to calculate the time to failure (TTF).

$$TTF = C\mathrm{e}^{\frac{E_\mathrm{a}}{k_\mathrm{B}T}} \tag{1}$$

In equation (1), C is a case specific constant, E_a the failure mechanism specific activation energy, k_B the Boltzmann constant and T the absolute temperature.

The link between TTF at operating temperature and the TTF at higher test temperature is given in equation (2)

$$TTF_\mathrm{operating} = A_T TTF_\mathrm{test} \tag{2}$$

$TTF_\mathrm{operating}$ and TTF_test can be calculated by equation (1) using $T_\mathrm{operating}$ and T_test. Therefore, the acceleration factor A_T can be calculated by equation (3).

$$A_T = \frac{TTF_\mathrm{operating}}{TTF_\mathrm{test}} = \mathrm{e}^{\left[-\left(\frac{E_\mathrm{a}}{k_\mathrm{B}T}\right)\left(\frac{1}{T_\mathrm{test}}-\frac{1}{T_\mathrm{operating}}\right)\right]} \tag{3}$$

The acceleration factor allows to calculate an equivalent test time (ETT) for each operating time at a specific operating temperature for a specific failure mechanism by equation (4)

$$t_\mathrm{operating} = A_T \times ETT \tag{4}$$

Table II contains the ETT for a failure mechanism with the activation energy of 0.7 eV (see Table III). The ETT is the time needed to achieve the same degree of degradation within the sample at test condition as in operating conditions during operating time. The test conditions are given by the HTOL test for grade 0, meaning 1,000 h at 150 °C ambient temperature. An additional self-heating of 20 °C of the device is assumed for the test condition and operating condition to derive the junction temperature (T_junction).

TABLE II
8,000 H OPERATING TIME TEMPERATURE SPECTRUM WITH ETT FOR HTOL WITH 1000 H AT 150 °C AMBIENT TEMPERATURE

T_ambient [°C]	T_junction [°C]	$t_\mathrm{operating}$ [h] from MP	ETT at T_ambient 150 °C (T_junction 170 °C) [h]
-35	-15	480	10^{-3}
28	48	1,600	2
81	101	5,200	177
125	145	640	214
130	150	80	33
Total time [h]:		8,000	426

Assuming that the damage is cumulative, the acceleration model can be used to calculate a total ETT. For failure mechanisms that do not show self-healing effects, this concept has been experimentally proven by Hirler et al. [5]

With this information, it is now possible to correlate the HTOL test condition with the exemplary mission profile.

The calculation of the ETT for different failure mechanisms must be done to estimate if the AEC-Q100 covers standard lifetime requirements. Three examples for typical semiconductor devices failure mechanisms with their activation energies are given in Table III [6]. It should be noted, that the values of E_a for different failure mechanisms are spread over an even wider range than reflected in Table III.

TABLE III
ACTIVATION ENERGIES FOR DIFFERENT FAILURE MECHANISMS [6]

Failure mode	Failure mechanism	E_a[eV]
A	H_2 diffusion, Mold compound oxidation	0.45
B	TDDB, Used as standard	0.70
C	Al and Cu stress migration, Intermetallic Kirkendall voiding	1.10

Table IV shows the resulting ETT for the spectrum given in Table I with an operating time of 8,000 h. The ETT has been calculated for three activation energies representing three different failure mechanisms.

TABLE IV
ETT FOR HTOL AT 150 °C AMBIENT TEMPERATURE FOR THE SPECTRUM GIVEN IN TABLE I

Failure mode	E_a [eV]	ETT [h]
A	0.45	972
B	0.70	426
C	1.10	161

The ETTs in this example are lower than the test time of 1,000 h that is required to pass the HTOL test.

This means the AEC-Q100 covers the standard lifetime requirements with 8,000 h operating time, but does it cover the future lifetime requirements?

B. *Increasing operating times*

While the results of the previous subsection are valid for an ECU that is only active during driving operation, new requirements and new calculations are necessary for systems that are also in use ("on") during non-driving operation.

An example from the field of electro mobility is the onboard battery charger. This system is also active when the car is charged by an external source resulting typically in an increase of the operating time by a factor four, as calculated below.

It is assumed that the car drives 300,000 km in 15 years. The resulting daily mileage is around 55 km. The specification of a VW e-Golf [7] is used for further calculations. It has a power consumption of 12.7 kWh per 100 km, therefore the daily power consumption is 7 kWh. The most time consuming method to charge the battery is the use of a standard household supply box with a power limitation of 2.3 kW. Under this condition, it takes 3.76 h per day to charge the battery. The result is a charging time of 20,600 h during 15 years. Combined with the driving operation time, the total operating time the onboard charger needs to withstand is 28,600 h. An additional consumption and therefore additional charging time results from comfort devices like multimedia systems and air-condition. Therefore, the estimated operating time is increased to 40,000 h for further calculations.

Furthermore digitalization, car-to-x communication and autonomous driving will lead to an “always-on” scenario in the future. This results in operating times of more than 120,000 h. Also in the field of electro mobility, permanent operating is a common condition for some applications like the surveillance of the high voltage systems.

C. Limitation of current standard qualification

Does the AEC-Q100 cover the new upcoming extended lifetime requirements? To answer the question the ETTs are calculated once again. This time a temperature spectrum for 40,000 h operating time is used. Table V shows a possible spectrum.

TABLE V
BASED ON ZVEI “AUTOMOTIVE APPLICATION QUESTIONNAIRE FOR ELECTRONIC CONTROL UNITS AND SENSORS [4]

T_{ambient} [°C]	Operating time ($t_{operating}$) [h]
-35	1,000
28	9,400
81	26,000
125	3,200
130	400

Again an additional self-heating of 20 °C is included in the calculation of the ETT. The HTOL according to AEC-Q100 grade 0 would cover these lifetime requirements if the ETT was equal to or below 1,000 h at 150 °C ambient stress temperature.

TABLE VI
HTOL ETT AT 150 °C AMBIENT TEMPERATURE FOR THE SPECTRUM GIVEN IN TABLE V

Failure mode	E_a [eV]	ETT [h]
A	0.45	4,877
B	0.70	2,131
C	1.10	803

The results in Table VI clearly show that the test time given in the AEC-Q100 does not cover these requirements for failure mechanisms A and B.

The process to handle lifetime requirements which are not covered by the stress tests of the AEC-Q100 is described in the appendix 7 of the standard. The appendix 7 includes a three phase flow with the following sections: 1) Basic calculation to check if the standard test conditions are sufficient to cover a mission profile. If not, then 2) set up a customer specific qualification test plan (extending the test durations) according to the mission profile. If this is not possible, 3) perform a model and data based lifetime validation following the Robustness Validation methodology.

In the ideal case, a qualification standard should cover the majority of application lifetime requirements. In that case, the standard will fulfill the role of a primary development target concerning reliability for the device manufacturer. Otherwise, there will be a significant number of customer specific lifetime requirements to be taken into account. This results also in customer specific qualifications for each case.

To understand why a customer specific qualification should be an exception, a look at the consequences is needed. From a process point of view the qualification is located at the end of the development flow. At this point of the development process, changes in the product and its manufacturing technology are time and cost intensive which might make them practically impossible. To outline the consequences the time dependent dielectric breakdown (TDDB) is used as an example. If the TDDB is critical for the reliability, the device manufacturer has two solutions, he can either make the gate oxide thicker or he can use a different gate oxide material. Changing the gate oxide thickness or using a different material results in a change of electrical properties, therefore it has a strong impact on the layout of the device. Also, these changes result in a change of the production process at wafer level. This change would affect all products manufactured in that technology. Therefore, it might not be possible to implement the change for this single product to fulfill the customer requirements.

Even if the product would meet the qualification requirements, each additional qualification to an already finished product would need time to be performed. This results in extra costs and project delays.

The appendix 7 of the AEC-Q100 was meant to deal with exceptional cases, but with the new requirements the exception will become the common case. Therefore, new standard methods are needed to cover the future.

III. CONCEPTS TO FACE THE NEW REQUIREMENTS

The previous section dealt with the limitations of the existing standard. In this section, it is discussed how to deal with the upcoming new lifetime requirements.

The first solution that one might think of is to reduce the lifetime requirement for a car to a lifetime lower than 15 years. At first sight, this has several benefits like always having up to date electronics and higher sale-figures for the car manufacturer. While this a valid business model in consumer electronics, it is not valid in the car industry due to the high price of a car. The typical customer is not willing to buy a new car every two years like it is common with mobile phones.

Another solution might be a replacement strategy which allows an easy replacement of electronic parts if their end of life is reached. Since ECUs are highly specialized electronics systems, the costs are significantly higher compared to consumer electronics that are sold million times. The storage of the exchange parts and labor costs for the exchange results in additional costs. Therefore, the replacement costs would be high, which is also something the costumer won’t accept. Since these two solutions are not practicable, the automotive industry has to face the increase in operating times and find a solution on how to deal with the upcoming new lifetime requirements in a standard.

In Fig.1, the challenge emerging from the megatrends of the automotive industry is illustrated. Lifetime requirements during the combustion engine era were typically covered by the AEC-Q100. This is no longer the case for the upcoming lifetime requirements of the new electric vehicle era. Therefore, an extension of the AEC-Q100 would support the standard to be a sufficient enabler to overcome the future challenges. Only with a standard that covers most common lifetime requirements, it is possible to gain back the transparency and comparability that is linked to a standardized qualification.

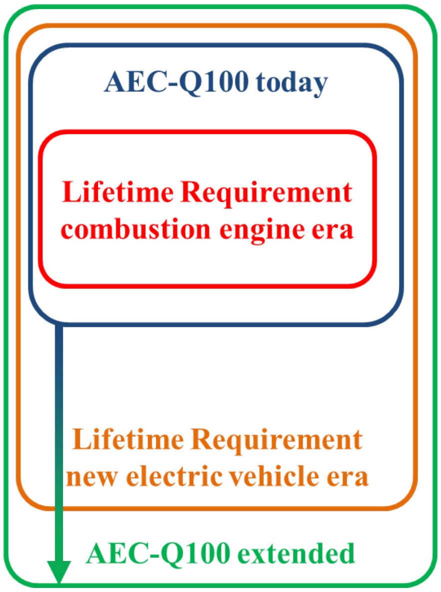

Fig. 1. Illustration of the necessary extension of the AEC-Q100

Three solutions to extend the existing standard will be discussed in detail in the following sections. First will be the extension of the test conditions, second will be Robustness Validation and the third solution will be extending the AEC-Q100 with standardized extended lifetime requirements, representing the new era. Those might be represented in the form of mission profiles.

A. Concept of extended test conditions

One method to cover increasing lifetime is to derive extended test conditions from the mission profile according to appendix 7. This must be done case by case. It might be a possible solution to standardize such test conditions for common use. The pass criteria for the test of zero failures out of 3x77 samples is assumed to stay unchanged in this case.

There are two ways to extend the test conditions in a way that they cover longer operating times. One is to increase the test time, the other is to increase the stress level (e.g. the temperature during stress tests). Both appear to be an easy solution to cope with longer operating times.

For the temperature spectrum in Table V, the target values for extending the test time can be derived from Table VI. It shows that if we want to keep the test temperature at the same level as today, we need to extend the test time to almost 5,000 h to cover the temperature spectrum given in Table V.

A closer look on the ETT in Table VI helps to understand the consequences of extending the test time. The ETT for failure mechanism A is almost five times longer than the ETT for failure mechanism C, but during test on product level both are activated simultaneously. As a consequence, the product must be developed to withstand the ETT for failure mechanism A to pass the qualification. This results in an unnecessary high reliability target with respect to failure mechanism C. In seldom cases, this does not cause any additional efforts, but commonly there are two possible outcomes. Either, it is not possible from a technical point of view to develop the product in a way that failure mechanism C is covered for conditions five times higher than needed in real conditions, or development and production efforts are needed to extend the product capabilities beyond the application needs. These efforts are commonly called over-engineering and in most cases this is connected to higher cost and therefore shall be avoided.

Instead of extending the test time, increasing the stress level (in case of HTOL the test temperature) might also be a solution to cover the extended operating times. Since the acceleration factor calculated in (3) is dependent upon the test temperature, it is possible to calculate the necessary test temperature if the test time should not exceed 1,000 h.

TABLE VII
EQUIVALENT TEST TEMPERATURE FOR HTOL WITH 1,000 H TEST TIME FOR SPECTRUM GIVEN IN TABLE V

Failure mode	E_a [eV]	Equivalent test temperature [°C]
A	0.45	219
B	0.70	169
C	1.10	147

Table VII shows a necessary test temperature of 219 °C is needed to cover failure mechanism A within 1,000 h.

But with increasing the temperature, there is the risk that failure mechanisms, which are not relevant in the real use conditions, are activated during the test and can lead to a failure of the qualification. Specifically, package materials are typically developed to withstand a temperature up to 175 °C, therefore higher test temperatures will lead to failures of the package. As a result, the package must be developed to meet the test conditions and not the use case and hence again over-engineering is the consequence.

To summarize, the main goal of a product qualification according to a standard is to make the robustness and test method transparent to the customer. Just extending the test conditions keeps this transparency and it is easy to communicate the results of the qualification. For technologies that do have enough margin for the failure mechanisms that are tested longer than needed, this is a valid concept. But the biggest disadvantage of this method is that there is a high risk that the product is developed to meet the standard and not the real use conditions.

B. Concept of Robustness Validation

The Robustness Validation [8] is an adaption of the concept of knowledge based qualification (KBQ) [9] to the automotive environment.

Part of the concept of Robustness Validation as well as KBQ is to have a deep understanding of the product and everything that influences its reliability. Hence, the aim is to obtain enough data for all relevant failure mechanisms and to extract a sufficient model of the reliability behavior over time. Fig. 2 shows a typical bathtub curve [10] which represents the quantified failure rate over lifetime. The bathtub curve consists of three sections. Those are the early failure rate at the beginning of the lifetime, the constant failure rate which is typical for the useful life of the product and the wear-out region at the end of the life. Added in this bathtub curve are the schematic efforts for product qualification and Robustness Validation for the device manufacturer.

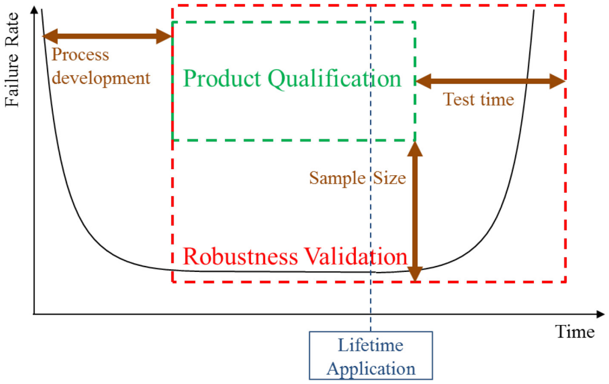

Fig. 2. Bathtub curve to illustrate the aim of Robustness Validation

The aim of product qualification is to prove a certain level of reliability and lifetime. This information shall be provided in a transparent way to make it easily assessable for the customer. Therefore, it covers a certain failure rate over a limited timeframe, which are dependent on the specified (customer) requirements. While the time frame which is covered is dependent on the test time, the covered constant failure rate is dependent on the tested sample size.

On the contrary, Robustness Validation is a method to understand the failure behavior. It can be used to determine the level of the random failure rate and the time when the wear-out failures become significant. Therefore, it is ideal for a technology qualification.

The avoidance of early failures is not addressed within Robustness Validation but is part of the process development, process control and final test (including burn in if necessary).

It is necessary to understand which parameters influence the failure behavior to use Robustness Validation during the technology and product development. With this knowledge, it is possible to optimize the product to meet the reliability requirements sufficiently and without unnecessary margin.

How is Robustness Validation performed? The basic steps to achieve the perfect lifetime behavior model are shown in Fig. 3.

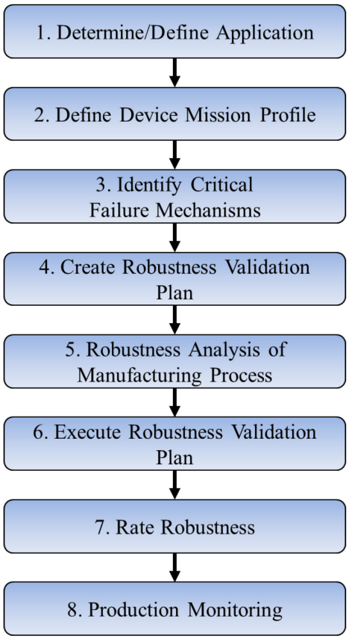

Fig. 3. Simplified process flow for Robustness Validation. Based on [9]

The basic idea is to set up application specific requirements and perform a product specific risk analysis. The goal is to get a robust product that sufficiently fits the reliability requirements which are given by the application.

The first step is to define a realistic mission profile. After the mission profile is set up, an analysis of the critical failure mechanisms is performed. The acceleration models have to be determined. With these, the stress test conditions can be calculated and a test plan can be set up. The last step is to perform the validation plan. This can be a qualification according to the mission profile specific test plan, or it can be done with generic data derived from test vehicles or reference products.

Robustness Validation is a method to fully understand what the product's capabilities are and how they can be optimized. Therefore, as a result the product will fulfill the requirements and the test method used will cover these. Robustness Validation is a highly flexible method. A strong feature of this method is that over-engineering is avoided and the test plan will cover the requirements.

To perform a Robustness Validation, a mission profile is needed from the beginning of the development. The quality of the mission profile determines how efficiently the advantages of this method can be used. Hence, the customer needs to be involved from the beginning if the product shall meet the customer's requirements. While this is the case when developing leading-edge semiconductor together with the customer, this is not necessarily the case for common products, since they are often designed for a broad variety of customers.

In addition, a deep understanding of semiconductor physics, the product design and the failure mechanisms are needed on the manufacturer's side.

It requires significantly more effort by the customer to assess the results of a Robustness Validation in comparison to an AEC-Q100 standard test plan.

Therefore, Robustness Validation is a method that is ideal for technology development and qualification, but not for product qualification.

C. *Concept of standardized extended lifetime requirements*

Beside extending the test conditions or performing a Robustness Validation, using standardized extended lifetime requirements (SELR) is a possible solution to extend the AEC-Q100.

The idea behind this concept is that instead of many application and customer specific extended lifetime requirements, a set of SELR is created and added to the standard in the form of mission profiles. These should cover almost all new common use cases that can be identified. For the requirements that were already covered by the AEC-Q100, nothing changes.

In section III A, it was shown that development and qualification based standard test conditions insufficiently cover the lifetime requirements for each failure mechanism, therefore a development and qualification based on mission profiles is more effective.

Why is it an advantage to standardize the lifetime requirements (i.e. mission profiles)? Fig. 4 points out the disadvantages of using non-standardized (i. e. customer specific) mission profiles in the product development.

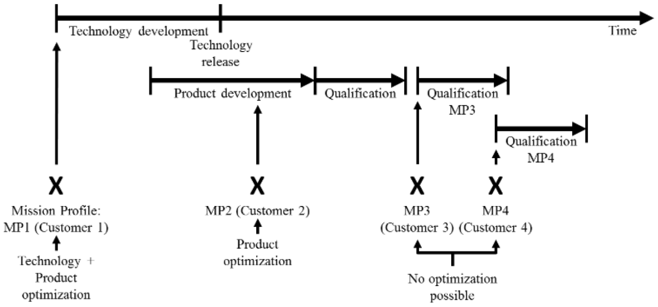

Fig. 4. Development flow with non-standardized mission profiles.

A typical product development is executed with a lead customer with mission profile MP1. During the product life cycle, various other customers may ask the manufacturer if the product can fulfill their individual mission profiles (MP2 to MP4). The later in the product development the customer mission profiles are communicated to the device manufacturer, the fewer are the possibilities to optimize the product to meet the additional customer specific lifetime requirements. It might even be the case that the requirements cannot be fulfilled, since the product is already in production. Furthermore, each additional customer specific qualification causes additional costs and delay.

In contrary, if it would be possible to replace MP1 to MP4 by standardized lifetime requirements, the device manufacturer would be able to overcome these constraints. Furthermore, the costumer has a guarantee from the device manufacturer that these extended lifetime requirements are fulfilled by the product if it is qualified according to the extended AEC-Q100 (see Fig 1.). This promotes the transparency and supports the communication between manufacturer and customer.

One method to qualify SELR is to extract standardized extended test conditions from those. As pointed out in section III A, this method is not always sufficient enough to cover the lifetime requirements. However, with the use of SELR, the device manufacturer is free to use suitable methods like generic data, test vehicle based concepts or Robustness Validation-like approaches if it is technically justified.

With the help of industry wide accepted standardized extended mission profiles, the semiconductor device manufacturer is not dependent upon customer specific mission profiles. Today, the manufacturer often does not have sufficient customer lifetime requirements at the start of the development. In this situation, the manufacturer has to evaluate the lifetime requirements from his own knowledge. The customer specific requirements are often communicated at a late stage of development. As shown in Fig.4, this can lead to additional customer specific qualifications. With industry wide accepted SELR, the manufacturer has a reliable goal for development from the beginning of the development. For common devices, he can now develop products with confidence that a wide range of customers will accept the standardized mission profiles for their use.

Besides having a goal for development, it is now possible to perform parts of the Robustness Validation for platform products that are not costumer specific. Since the manufacturer can use the SELR from the beginning of the development, he is able to perform a failure mechanism analysis and set up product specific test plans like those defined in Robustness Validation. The result is a kind of standardized Robustness Validation. Additionally, this saves costs and time, because the multiple qualifications as depicted in Fig. 4 have to be performed only once.

To demonstrate the advantages of SELR, the calculation from subsection II.C and the ETT of Table VI are reused.

It is assumed that there are test data available showing that the expected operating lifetime for the product with respect to failure mechanism C is 2,200 h at 150 °C.

With an extended test time of 2,200 h, it is now possible to cover failure mechanism B and C. But how is failure mechanism A covered? Extending the test time is not possible, since failure mechanism C will lead to a failure of the product before failure mechanism A becomes critical. But since the mission profile is known from the start of the development, it is a possible solution to use test vehicles which are able to cover all failure mechanisms over the test time of failure mechanism A, either in a manner that the materials that cause failure mechanism B and C are eliminated or have been modified to withstand the test time. With this test vehicle, generic data can be obtained and used to make a solid prediction that the product will fulfill the requirements.

This example contains a combination of extended test conditions with a Robustness Validation like approach for critical failure mechanisms that cannot fully be covered in a product qualification.

If the standard mission profiles are part of the AEC-Q100 as extended lifetime grades, the vehicle and ECU manufacturer can still rely on the AEC-Q100 as a first proof that a product fulfills automotive standards. And the semiconductor manufacturer has the possibility to qualify a product without the input of a customer.

Extending the existing standard with a set of standardized extended lifetime requirements SELR eliminates the disadvantages of standardized test conditions and those of Robustness Validation. It combines the advantages of both methods to a flexible but standardized solution. But it has to be kept in mind that without a widespread acceptance of the SELR and a responsible use of this method from device manufacturers, this method will not work.

IV. CONCLUSION

Qualification with standardized test conditions has been the standard method for automotive semiconductor devices in the last decades.

Electro mobility, digitalization and autonomous driving bring a disruptive change in lifetime requirements for automotive electronics. It was shown that the standard methods of the last decades cannot cover the new requirements.

In this paper, three possible solutions to deal with these challenges were presented. These are extending the test conditions, performing Robustness Validation and adding standardized extended lifetime requirements to the standard. A short comparison is listed in Table VIII. "+" indicates an advantage for this point, "-" indicates a disadvantage, "0" no recognizable change compared to AEC-Q100 and the appendix 7.

TABLE VIII
COMPARISON OF POSSIBLE SOLUTION TO HANDLE UPCOMING LIFETIME REQUIREMENTS.

	Extended test conditions	Robustness Validation	Standardized extended lifetime requirements (SELR)
Duration	0	-	+
Execution effort	+	-	+
Accuracy	-	+	0
Risk of over-engineering	-	+	+
Flexibility	-	+	0
Transparency	+	-	+

The comparison reveals that extending the test condition is a very transparent method to communicate but is linked to the risk of developing a product to meet the standard and not to meet the operating conditions.

Robustness Validation on the other hand presents a flexibility that results in a product that is optimized to meet the operating requirements. However, the assessment done during Robustness Validation can be very complex and is complicated to communicate in a transparent way.

Using standardized extended lifetime requirements SELR combines the advantage of being easy to communicate and the advantage of helping to develop products that are optimized to meet the operating requirements. But a wide spread acceptance of the SELR is needed.

Therefore as a next step, a proposal for a set of standardized extended lifetime requirements SELR has to be made and discussed within the automotive industry to achieve a widespread acceptance.

ACKNOWLEDGMENT

This contribution has been funded as part of the project autoSWIFT (project label 16ES03) within the research program ICT 2020 by the German Federal Ministry of Education and Research (BMBF).

REFERENCES

[1] U. Abelein, H. Lochner, D. Hahn, S. Straube, „Complexity, quality and robustness - the challenges of tomorrow's automotive electronics", DATE 2012 Proceedings of the Conference on Design, Automation and Test in Europe, Pages 870-871, DOI: 10.1109/DATE.2012.6176573

[2] Automotive Electronics Council (AEC), "Failure Mechanism Based Stress Test Qualification for Integrated Circuits", AEC-Q100-REV-H, September 11th 2014

[3] Volkswagen, Internal company standard VW 80000 "Electric and Electronic Components in Motor Vehicles up to 3.5 t; General Requirements, Test Conditions, and Tests", October 2017

[4] German Electrical and Electronic Manufacturers Association (ZVEI), "Automotive Application Questionnaire for Electronic Control Units and Sensors", October 2006

[5] A. Hirler, J. Biba, A. Alsioufy, T. Lehndorff, T. Sulima, H. Lochner, U. Abelein, W. Hansch, „Evaluation of effective stress times and stress levels from mission profiles for semiconductor reliability", Microelectronics Reliability Volume 76–77, Pages 38–41, September 2017, DOI: 10.1016/j.microrel.2017.06.022

[6] JEDEC Solid State Technology Association, JEDEC Publication JEP-122G "Failure Mechanisms and Models for Semiconductor Devices", October 2011

[7] Volkswagen, VW e-Golf customer sales data sheet, viewed November 22nd 2017

[8] German Electrical and Electronic Manufacturers Association (ZVEI), "Handbook for Robustness Validation of Semiconductor Devices in Automotive Applications". 3rd edition, May 2015

[9] JEDEC Solid State Technology Association, JEDEC Publication JESD-94B "Application Specific Qualification Using Knowledge Based Test Methodology", September 2011

[10] J.W. McPherson, "Reliability Physics and Engineering", Springer International Publishing Switzerland, 2013, DOI: 10.1007/978-3-319-00122-7