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# Application of ISO 26262:2011-2012 to semiconductors —

## Part 2: Application of hardware qualification

*Application de l'ISO 26262:2011-2012 aux semi-conducteurs —*

*Partie 2: Application de la qualification du matériel*



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# Foreword

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The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 32, *Electrical and electronic components and general system aspects*.

ISO/PAS 19451 consists of the following parts, under the general title *Road vehicles — Application of ISO 26262:2011-2012 to semiconductors*:

— *Part 1: Application of concepts*

— *Part 2: Application of hardware qualification*

# Introduction

This document is an informative guideline which provides users of the ISO 26262 series of standards recommendations and best practices which can be utilized when applying ISO 26262 to semiconductor components and parts. This document was created by a group of industry experts including semiconductor developers, system developers, and vehicle manufacturers in order to clarify concerns seen after the initial release of the ISO 26262 series of standards and when possible to align on common interpretations of the standard.

This document serves to augment the existing normative and informative guidance in the ISO 26262 series of standards. The approach is similar to that taken in writing ISO 26262-10:2012, Annex A, "ISO 26262 and microcontrollers," with extension to additional types of semiconductor technologies and relevant topics.

# Application of ISO 26262:2011-2012 to semiconductors —

# Part 2: Application of hardware qualification



## 1 Scope

This document is applicable to developers who are evaluating the use of hardware qualification for semiconductor elements according to ISO 26262-8:2011, Clause 13.

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16750-1, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 1: General*

ISO 26262-1, *Road vehicles — Functional safety — Part 1: Vocabulary*

ISO 26262-4, *Road vehicles — Functional safety — Part 4: Product development at the system level*

ISO 26262-5:2011, *Road vehicles — Functional safety — Part 5: Product development at the hardware level*

ISO 26262-8:2011, *Road vehicles — Functional safety — Part 8: Supporting processes*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 26262-1 apply.

## 4 Hardware qualification

Hardware qualification is a process in which it is determined if the hardware can fulfil the allocated requirements of a given design. There are multiple ways in which hardware qualification can be defined and applied. Unfortunately ISO 26262-1 does not include a formal definition of hardware qualification. Due to the variety of usages of the phrase "hardware qualification" there can be perceived ambiguity in ISO 26262-8:2011, Clause 13 dependent on the background of the reader.

Throughout the remainder of this document the phrase "hardware qualification" is used to reference "Qualification of Hardware Components" according to ISO 26262-8:2011, Clause 13. Activities used to qualify hardware for compliance to relevant automotive quality standards for safety related or non-safety related hardware components and parts are described as "standard qualification."

## 5 How is "standard qualification" differentiated from ISO 26262 hardware qualification?

### 5.1 Standard qualification

ISO 26262-8:2011, Clause 13 does not specify a particular standard or set of standards which should be applied for standard qualification. Several examples are listed as understood to be relevant to current state of the art. The user of the standard should take care to ensure that any standard or set of standards to be applied for hardware qualification are considered state of the art at the time of development.

ISO 16750-1 is one of the references suggested to carry out a standard qualification. It gives requirements to qualify suitability of a product for automotive applications. Tests proposed by ISO 16750-1 are meant to stress the product at the boundaries of an automotive scenario to ensure its robustness in terms of e.g. temperature and voltage ranges. Qualification according to ISO 16750-1 is meant for generic automotive usage.

AEC-Q100[7] provides details of a number of accelerated test methods which could be applied to perform standard qualification. The main AEC-Q100 document is supplemented by multiple annexes which each focus on a specific test method for accelerated testing of particular failure modes. The Automotive Electronics Council provides other standards focusing on discrete semiconductors (AEC-Q101 series) and passive components (AEC-Q200 series) which may be relevant dependent on the type of element under consideration.

Annex A provides excerpts from an example standard qualification plan used by a supplier of semiconductors to the automotive market. Tests have been selected from a number of quality standards in order to demonstrate suitability for use in automotive applications. In this example qualification tests from AEC, JEDEC, and US military standards are referenced. Exact contents of a standard qualification plan will vary from supplier to supplier and should be based on testing of specific failure modes relevant to the type of circuitry implemented and the specific technology used.

NOTE If experimental data from standard qualification is to be used as a source for failure rates in calculation of functional safety metrics according to ISO 26262-5:2011, 8.4.3 then appropriate failure mechanisms and sample sizes are considered.

### 5.2 ISO 26262 hardware qualification

Qualification according to ISO 26262-8:2011, Clause 13 requires that a dedicated qualification argument (report) should be provided for the hardware component or part with respect to the allocated safety requirements. The qualification argument demonstrates that the applied analyses and tests provide sufficient evidence of compliance with the allocated safety requirement(s). The relevant failure modes and failure mode distributions are also included in order to evaluate the validity of the argument.

Some results of standard qualification may satisfy the requirements of the hardware qualification activity. A gap analysis could be performed to identify requirements of hardware qualification which are not satisfied by standard qualification. If no gap is identified, this analysis should be a sufficient argument to claim compliance with ISO 26262-8:2011, Clause 13. This is supported by ISO 26262-8:2011, 13.4.5.

In some cases data generated from standard qualification activities can be used to provide failure rates and failure distributions for a part or component. If this approach is taken, it is done in accordance with ISO 26262-5:2011, 8.4.3. If additional testing is used to develop failure rates for safety analysis the developer can consult a relevant industry publication such as the ZVEI or SAE Handbook of Robustness Validation of Semiconductor Devices in Automotive Applications[9][10] for suggestions in the selection and application of relevant tests.

The qualification according to ISO 26262-8:2011, Clause 13 may also include verification and testing plans for the functional aspects of the hardware component and part. These verification activities are not always performed by the supplier, particularly in the case of COTS or SEooC parts or components. If performed, these activities are part of the qualification and safety case argumentation.

## 6 Why is ISO 26262 hardware qualification applied?

### 6.1 Hardware qualification as a method of design verification of allocated safety requirements

As stated in the NOTE of ISO 26262-4:2011, 7.4.5.2, hardware qualification according to ISO 26262-8:2011, Clause 13 may provide evidence of compliance to allocated safety requirements.



 

In this context the output of the hardware qualification activity can be used as an input to the item integration and test activity.

ISO 26262-5:2011, 6.4.6 states that hardware qualification is an accepted method for design verification of the hardware of the item or element, including environmental conditions, specific operational environment, and component specific requirements.

As stated in ISO 26262-5:2011, 10.2, hardware qualification and associated testing is not the same as hardware integration and testing.

As both ISO 26262-5:2011, Clause 10 and ISO 26262-4:2011, Clause 8 have as an objective to ensure by testing the compliance of the developed hardware and integrated elements with the (allocated) safety requirements, qualification is an alternative or specific means to testing. It can be used for hardware components and parts lower in the design hierarchy and in cases where it can be a sufficient means to provide evidence of the compliance to the allocated safety requirements, while further integration tests may be needed at higher levels in the design hierarchy.

Figure 1 illustrates how hardware qualification interacts with other verification activities in the context of ISO 26262. According to ISO 26262-5:2011, 6.4.6 there are multiple options to provide design verification, including by hardware qualification (see ISO 26262-8:2011, Clause 13) and by hardware integration and testing (see ISO 26262-5:2011, Clause 10). The planning of the verification activity is illustrated as occurring before initiation of the hardware design (see ISO 26262-5:2011, Clause 7). The results of the hardware qualification activity then become inputs to the hardware integration and testing activity (see ISO 26262-5:2011, Clause 10) or the item integration and testing activity (ISO 26262-4:2011, Clause 8), dependent on the level of hierarchy of the element under qualification. The standard qualification report, though not directly a work product of hardware qualification according to ISO 26262-8:2011, Clause 13, is used as an input to the initiation of product development at the hardware level (ISO 26262-5:2011, Clause 5) if available when product development at hardware level is initiated.



 

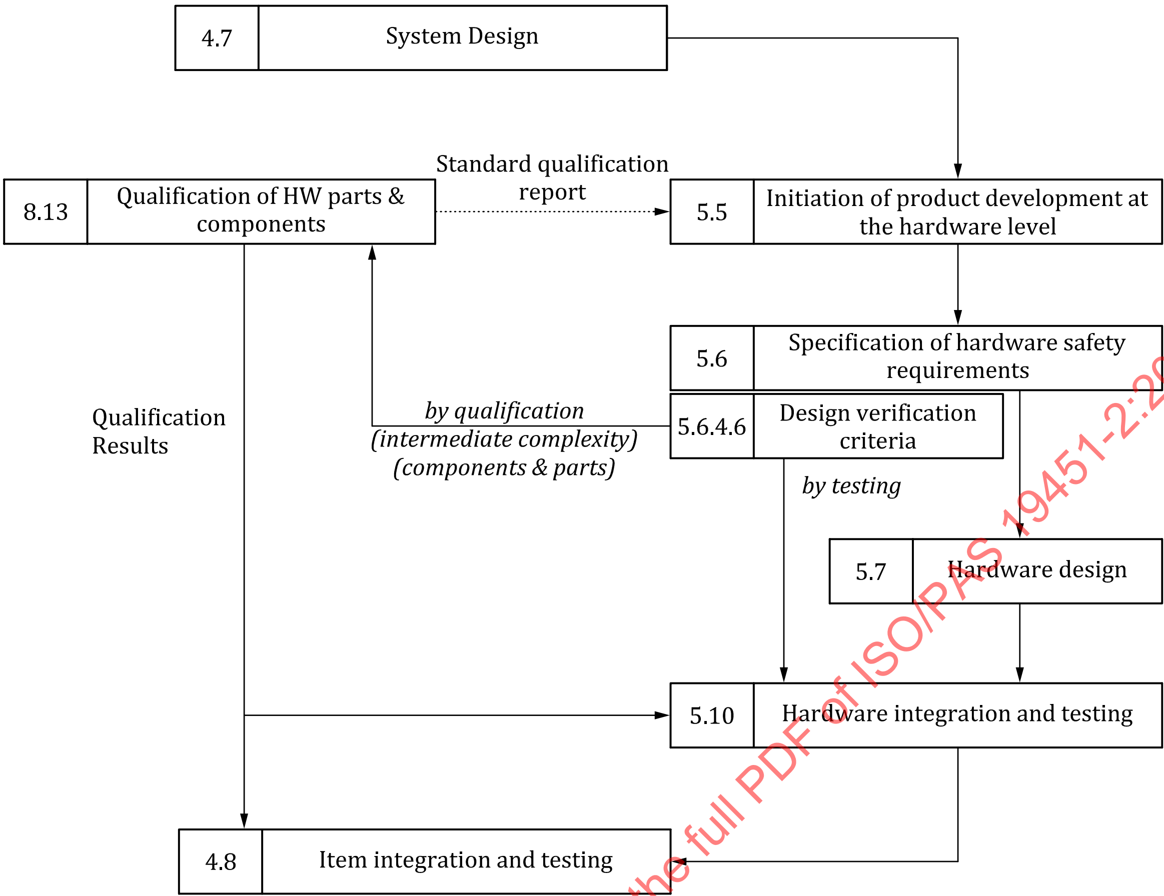


**Figure 1 — Interactions with hardware qualification**



## 6.2 Hardware qualification as a method to justify the use of components or parts which have not been developed according to ISO 26262

According to ISO 26262-8:2011, 13.4.2.1, one of the goals of hardware qualification is to confirm that a component or part under qualification has adequate functional performance for the purposes of the safety concept. This opens the possibility of hardware qualification being used to qualify the use of intermediate level hardware elements not developed according to ISO 26262 as mentioned in Reference[8].

Hardware qualification should not be seen as a cheaper alternative to ISO 26262 compliance for hardware parts and components. There are cases where the application of a subset of ISO 26262 requirements for hardware parts and components could be viable, but concrete argumentation is needed based on specific allocated safety requirements. This interpretation can be considered a specific case of hardware qualification to verify the safety requirements allocated to hardware components which were not developed according to ISO 26262.

As stated in ISO 26262-10:2012, 9.1, hardware qualified parts and components are different from those which are developed according to ISO 26262-5 as Safety Elements out of Context (SEooC). Hardware qualification enables the use of hardware components and parts not developed in compliance with ISO 26262 to be used in ISO 26262 compliant elements or items. For semiconductor suppliers, hardware qualification is crucial because of the large number of hardware components and parts developed before publication of the ISO 26262 standards which continue to be designed into new automotive safety related systems.

For an intermediate component (not developed according to ISO 26262) failure modes, failure rates, and diagnostic coverage of potential safety mechanisms can be provided by the supplier. The system integrator uses this information to determine whether the component qualifies for use in the safety related system as described in ISO 26262-4:2011, 8.4.3.2. The information needed to support this activity can be generated by standard qualification enhanced with additional qualification activities as described in ISO 26262-8:2011, Clause 13.

If a hardware component was not developed according to ISO 26262, then measures and techniques used to mitigate systematic failures can be deficient. Since the integration and testing specified in ISO 26262-5:2011, Clause 10 is intended to mitigate systematic failures, hardware qualification is expected to provide a similar level of systematic failure mitigation. Therefore, deficiencies in systematic failure mitigation at component level could be compensated by qualification testing and analyses of key functionalities.

### 6.3 Hardware qualification as a method to enable robustness validation

Hardware qualification according to ISO 26262 introduces additional activities to confirm the behaviour of a component or part in a specific implementation which are beyond the requirements of standard qualification. In the field of automotive reliability engineering there is a similar concept of robustness validation which performs additional qualification activities beyond standard qualification based on the specific use case and implementation.

Robustness validation activities are not required to implement ISO 26262 hardware qualification; they are one of many different solutions which are considered to meet ISO 26262 hardware qualification requirements. Developers who are interested to learn more about robustness validation methodologies for consideration in ISO 26262 hardware qualification can reference the ZVEI or SAE Handbook of Robustness Validation of Semiconductor Devices in Automotive Applications[9][10].

## 7 When is ISO 26262 hardware qualification applied?

### 7.1 Considering ISO 26262-8, Table 6

ISO 26262-8:2011, Table 6 provides guidance on the application of hardware qualification. The table has been recreated below as Table 1 with additional clarifications in footnotes to help guide the user in determining when hardware qualification is to be applied.

**Table 1 — Enhanced ISO 26262-8:2011, Table 6**

<table>
<tr><th rowspan="3">Activity</th><th colspan="4">Hardware part or component</th></tr>
<tr><th>Safety-related basic hardware part</th><th>Safety-related intermediate hardware part</th><th>Safety-related intermediate hardware component</th><th>Safety-related complex hardware component</th></tr>
<tr><td>(e.g. resistors, transistors...)</td><td>(e.g. gray code decoder)</td><td>(e.g. fuel pressure sensor)</td><td>(e.g. ECU)</td></tr>
<tr><td>Standard qualification</td><td>Applicable[a]</td><td>Applicable[a]</td><td>—</td><td>—</td></tr>
<tr><td>Qualification in accordance with ISO 26262-8:2011, Clause 13</td><td>—</td><td>Applicable[b]</td><td>Applicable[b]</td><td>—</td></tr>
<tr><td>Integration/test in accordance with ISO 26262-5</td><td>—</td><td rowspan="2">Applicable[c]</td><td rowspan="2">Applicable[c]</td><td>Applicable</td></tr>
<tr><td>Integration/test in accordance with ISO 26262-4</td><td>—</td><td>Applicable</td></tr>
</table>

[a] Refers to all qualification activities carried out for safety-related hardware components or parts used within the scope of ISO 26262 to address general functional performance, conformity of production, environnmental endurance and robustness.

[b] Refers to qualification of intermediate part and component contributing to a safety requirement in a given environmental and operating condition, to provide evidence of its suitability of being part of items, systems or elements developed in compliance with ISO 26262.

[c] The hardware part or component will be tested and integrated in accordance with ISO 26262-4 or ISO 26262-5, or both ISO 26262-4 and ISO 26262-5, depending on its level.

## 7.2 Standard qualification

As stated in ISO 26262-8:2011, 13.2, standard qualification is applicable to all safety-related hardware parts or components to be used in the scope of compliance to ISO 26262. Dependent on complexity of the element under qualification as well as whether it is a part or component, additional hardware qualification activities beyond standard qualification may be necessary.

NOTE ISO 26262-8:2011, Table 6 does not list standard qualification as being applicable to safety-related intermediate hardware components or safety-related complex hardware components. This is interpreted as meaning that standard qualification by itself without additional hardware qualification activities is not sufficient for such components.

## 7.3 Hardware qualification according to ISO 26262

Qualification according to ISO 26262-8:2011, Clause 13 is only to be applied to intermediate level hardware parts or intermediate level hardware components with dedicated functionality.

According to ISO 26262-10:2012, 9.1 hardware qualification per ISO 26262-8:2011, Clause 13 can be applied to a pre-existing element, i.e. intermediate hardware part or component regardless of whether it was developed according to ISO 26262.

Criteria on the applicability of this clause to different types of HW products are given as a) and b) of ISO 26262-8:2011, 13.4.1.1. The criterion of ISO 26262-8:2011, 13.4.1.1 b) is “the relevant failure modes of the component or part to be qualified shall be assumed to be verifiable by testing, analysis or both”. The “relevant failure modes” aid in classifying the complexity of hardware component. For example, if a hardware component featuring extensive functional integration is used in a very restricted way, such that a limited set of failure modes are safety related, then such component might be classified as having intermediate complexity.

NOTE 1 If the safety requirements (including operating conditions and environmental constraints) allocated to the same part or component remain the same across multiple system designs, the results of a hardware qualification activity can be re-used.

NOTE 2 Qualification of hardware components per ISO 26262-8:2011, Clause 13 does not have specific requirements based on the ASIL of safety requirements.

# 8 Challenges in application of ISO 26262 hardware qualification

## 8.1 Impact of complexity on hardware qualification

ISO 26262-8:2011, 13.2 introduces the concept of complexity as a determining factor to identify the type of qualification activity which should be applied to a hardware part or hardware component. Complexity is described as being either "basic", "intermediate", or "complex." As stated in ISO 26262-8:2011, 13.1, the objective of this chapter is limited to qualification of intermediate level hardware components. However, the standard does not clearly define "complexity." Examples given in ISO 26262-8:2011, 13.2 and Table 6, as summarized in Table 2, are used to evaluate complexity.

**Table 2 — References to complexity in ISO 26262-8:2011, Clause 13**

| Degree of Complexity | Examples Given in 13.2 and Table 6 |
|---|---|
| Basic hardware parts | Passive component<br>Discrete semiconductor<br>Resistors<br>Transistors |
| Intermediate hardware components and/or hardware parts | Sensors<br>Actuators<br>ASICs with dedicated functionality<br>Gray code decoder<br>Fuel pressure sensor |
| Complex hardware component | ECU |

Overall complexity is difficult to define and this document will make no effort to formally define the term. Instead, a collection of different aspects to consider when evaluating complexity is provided.

A key aspect of complexity is the number of fundamental design elements (sub-parts such as transistors, logic gates, etc.) integrated into the hardware component or hardware part. Complexity increases as the number of fundamental components increases. This position can be supported by the examples provided in ISO 26262-8:2011, 13.2 and Table 6.

EXAMPLE A resistor can easily be argued to have low design complexity as compared to an ECU, as it includes a smaller number of fundamental design elements.

The role which the element plays in the overall safety concept of the item should also be considered when classifying complexity of the element. This argumentation is supported by the statement by

ISO 26262-8:2011, 13.1, "... concerning their functional behaviour and their operational limitations *for the purposes of the safety concept*."

EXAMPLE A system on chip (SoC) component integrating many functions as separate parts is classified as a complex component and thus hardware qualification per ISO 26262-8:2011, Clause 13 would not apply. If only a subset of the integrated functionality, such as a single part, is safety related in a given system context and is readily verifiable, then it could be possible to consider this part as an intermediate hardware part and to qualify only that hardware part. Care should be taken to ensure that freedom from interference of the non-safety related parts is addressed.

Another approach is to classify the complexity of an element by analysing its operation as a black box. If it is possible to clearly understand the behaviour of the element considering only its inputs and outputs, then the element can be considered to have intermediate or lower complexity. If the element cannot be readily understood from a black box approach, then it could be treated as a complex element for the purposes of hardware qualification.

EXAMPLE The behaviour of a temperature sensor with a limited number of inputs and outputs can generally be deduced by black box analysis, which supports application as an intermediate (or lower) complexity hardware part. In comparison, the behaviour of a microcontroller with dozens of input and output pins may not easily be understood as a black box and could be considered a complex component and out of scope for hardware qualification. If the sensor includes a processor which only provides limited, fixed, and well understood functionality such as filtering sensor inputs, then it is possible to classify the sensor as an intermediate hardware component or part.

Dependent on interpretation followed and on differences in qualitative classification of complexity, different outcomes may result. Consider the case of a multi-core microcontroller with a high degree of functional integration which has only a minor role in the implementation of an item's safety concept. One interpretation could suggest that the microcontroller is a complex component, and thus hardware qualification per ISO 26262-8:2011, Clause 13 should not be applied. Another interpretation could suggest that the microcontroller is at best an intermediate component and thus hardware qualification per ISO 26262-8:2011, Clause 13 would be applicable. Both interpretations could be considered valid if supported by appropriate argumentation.

## 8.2 Impact of hardware part vs. hardware component taxonomy on hardware qualification

ISO 26262-8:2011, Table 6 introduces an additional challenge in the classification of a design element as a hardware part or a hardware component. According to ISO 26262-1, a hardware part is "hardware which cannot be subdivided" whereas a component is a "non-system level element that is logically and technically separable and is comprised of more than one hardware part or of one or more software units." The distinction between a hardware part and a hardware component is not always clear. Consider Table 3 which illustrates that abstraction is open to interpretation by different developers.



**Table 3 — Varying interpretations based on design abstraction**

| Developer | Level of abstraction | What is the lowest level hardware element which cannot be subdivided (a hardware part)? |
|---|---|---|
| Vehicle manufacturer | High | Any single packaged IC device |
| System developer | Medium | Any basic logical block such as a processor, memory, peripheral, ... |
| Semiconductor developer | Low | A low level functional block found in a logical block, such as a logic gate, logic register, SRAM bit, ... |
| Semiconductor process expert | Very low | A single N-channel or P-channel transistor device |

A single design element, implemented in a single design, could be classified separately as a part and as a component by two different developers if supported by appropriate argumentation. If considered an intermediate hardware part, then according to ISO 26262-8:2011, Table 6 standard qualification is