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PRE-STANDARD

Use of semiconductor devices outside manufacturers' specified temperature ranges

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

USE OF SEMICONDUCTOR DEVICES OUTSIDE MANUFACTURERS' SPECIFIED TEMPERATURE RANGE

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IEC-PAS 62240 has been processed by IEC technical committee 107: Process management for avionics.

The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document:
Draft PAS	**Report on voting**
107/3/PAS	107/8/RVD

Full information on the voting for the approval of this PAS Pre-Standard can be found in the report on voting indicated in the above table.

Introduction

Traditionally, industries that produce electronic equipment for rugged applications have relied on the military specification system for semiconductor device standards; and upon manufacturers of military-specified devices as device sources. This assured the availability of semiconductor devices specified to operate over the temperature ranges required for electronic equipment in rugged applications. Many device manufacturers have exited the military market in recent years, resulting in decreased availability of devices specified to operate over wide temperature ranges. Following are some typical temperature ranges at which devices are marketed:

Military:	-55°C to +125°C
Automotive:	-40°C to +125°C
Industrial:	-40°C to +85°C
Commercial:	0°C to +70°C

If there are no reasonable or practical alternatives, then a potential response is for equipment manufacturers to use devices in temperature ranges that are wider than those specified by the device manufacturer. If properly documented and controlled, this practice may be used by electronic equipment manufacturers to meet the design goals of their equipment.

This document prescribes practices and procedures to select semiconductor devices; to assess their capability to operate; and to assure their intended quality in the wider temperature ranges. It also prescribes the documentation of such usage.

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1. Scope

This document prescribes processes for using semiconductor devices in wider temperature ranges than those specified by the device manufacturer. It applies to any designer or manufacturer of equipment intended to operate under conditions that require semiconductor devices to function in temperature ranges beyond those for which the devices are marketed.

This document is intended for applications in which only the performance of the device is an issue. Even though the device is used at wider temperatures, the wider temperatures will be limited to those that do not compromise the system performance or application-specific reliability of the device in the application. Specifically, this document is not intended for applications that require the device to function at an operating or environmental stress level that significantly increases the risk of catastrophic device failure, loss of equipment function, or unstable operation of the device.

The use of devices outside the parameters specified by the device manufacturer is discouraged; however, such usage may occur if other options prove to be impossible, unreasonable, or impractical.

> Note: Alternate means of thermal uprating may have been performed prior to the implementation of this document by the equipment manufacturer. Rationale for decisions made may have been valid considering the application, semiconductor market conditions, experience with the particular component manufacturer, etc. at the times these decisions were made. Field performance using these methods also may validate their use, however, their continued use must take into account the risk of changes to the subject devices such as feature size reductions, material changes, etc.

2. References

2.1 Normative References

Not applicable.

2.2 Informative References

IEC PAS, Electronic Component Management Plans.

IEC 60134, Rating Systems for Electronic Tubes and Valves and Analogous Semiconductor Devices (1st Edition, 1961).

3. Terms and Definitions

Note: The terms *uprating* and *thermal uprating* are being used increasingly in avionics industry discussions and meetings, and clear definitions are included in this clause. They were coined as shorthand references to a special case of methods commonly used in selecting components for circuit design. This document describes the methods and processes for implementing this special case. All of the elements of these processes employ existing, commonly used engineering practices. No new or unique engineering knowledge is required to follow these processes: only a rigorous application of the overall approach.

The following terms and definitions are used herein and/or should be used when using devices outside the manufacturers' specified temperature ranges:

Absolute maximum ratings are limiting values of operating and environmental conditions applicable to any semiconductor device of a specific type as defined by its published data, which should not be exceeded under the worst possible conditions. These values are chosen by the device manufacturer to provide acceptable serviceability of the device, taking no responsibility for equipment variations, and the effects of changes in operating conditions due to variations in the characteristics of the device under consideration and all other electronic devices in the equipment. (From IEC 134, 1st Edition 1961).

Ambient temperature is the temperature of the environment in which a semiconductor device is operating.

Case temperature is the temperature of the surface of a semiconductor device package during operation.

Circuit Element Functional Mode Analysis: A documented analysis that determines minimums, ranges and maximums of all functional characteristics of the assembly with respect to the related functional parameters of devices being uprated.

Device capability assessment is the process of demonstrating that the device design is capable of providing the specified functionality, over the wider temperature range, for the required length of time. It assumes that the device has been qualified to operate within its specified temperature range, and includes additional testing or analysis to evaluate expected performance at the wider temperature range. Device capability assessment includes both performance and application-specific reliability.

Device quality assurance over the wider temperature range is the additional testing or analysis required to assure that each individual device is capable of operating successfully in the required wider temperature range.

ECMP are the initials for Electronic Component Management Plan.

Semiconductor devices are electronic devices that are not subject to disassembly without destruction or impairment of design use. They are sometimes called *electronic parts* or *piece parts*. Examples are diodes, integrated circuits, and transistors.

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Electronic equipment is any item, e.g., end item, sub-assembly, line-replaceable unit, shop-replaceable unit, or system produced by an electronic equipment manufacturer.

Junction temperature is the temperature of the active region of the device in which the major part of the heat is generated. (adapted from SEMATECH)

Manufacturer-specified parameter limits are the electrical parameter limits that are guaranteed by the device manufacturer when a device is used within the recommended operating conditions (see *Rating*).

Manufacturer-specified temperature range is the operating temperature range over which the device manufacturer guarantees the electrical parameters of the device. (see *Rating*).

Note: Manufacturer-specified temperature range is a subset of the recommended operating conditions.

May indicates a course of action which is permissible within the limits of this document.

determined for specific values of environment and operation, and may be stated in any suitable terms. (from IEC 60134).

Note: Limiting conditions may be either maxima or minima.

Parameter conformance assessment is a process for thermal uprating in which devices are tested to assess their conformance to the manufacturer-specified parameter limits over the target temperature range.

Parameter characterization is the process of determining the typical and limiting values of electrical parameters by testing representative samples at room and extreme temperatures over the manufacturer's specified temperature range.

Parameter re-characterization is a process for thermal uprating in which the device parameters are characterised over the target temperature range, leading to a possible re-specification of the manufacturer-specified parameter limits.

Rating is a value that establishes either a limiting capability or a limiting condition for a semiconductor device.

Recommended operating conditions are the ratings on a device within which its electrical specifications are guaranteed. (see *Rating*).

Shall indicates a mandatory requirement to be followed in order to conform to this document.

Should indicates that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain course of action is deprecated but not prohibited.

Stress balancing is a process for thermal uprating in which at least one of the device's electrical parameters is kept below its maximum allowable limit to reduce heat generation, thereby allowing operation at a higher ambient temperature than that specified by the device manufacturer.

Target temperature range is the operating temperature range of the device in its required application.

Thermal uprating is a process to assess the capability of a part to meet the performance requirements of the application in which the device is used outside the manufacturer's specified temperature range. (see *Uprating*).

Uprating is a process to assess the capability of a device to meet the performance requirements of the application in which the device is used outside the manufacturer's specification range.

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Wider temperature range is a target temperature range outside the manufacturer-specified temperature range. It may include temperatures that are higher or lower than the manufacturer-specified temperature range, or both.

Will expresses a declaration of intent.

4. Objectives

The objectives of this document are:

- To ensure that device usage outside the manufacturers' specified temperature ranges is done only with appropriate justification; and
- To ensure that, if it is necessary to use devices outside the manufacturers' specified temperature ranges, it is done with documented and controlled processes that assure the integrity of the equipment.

5. Using Devices Outside the Manufacturer's Specified Temperature Ranges

Devices used outside the manufacturers specified temperature range ***shall be*** selected (5.1), their capability is assessed (5.2), their quality is assured (5.3), and documented (5.4), as illustrated by the flow chart of Figure 1.

Note: The headings of this clause are keyed to the actions and decisions of Figure 1.

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5.1 Device Selection, Usage and Alternatives

The equipment manufacturer ***shall*** design so that, initially and throughout life, no absolute-maximum value for the intended service is exceeded for any device under the worst probable operating conditions with respect to supply voltage variation, equipment device variation, equipment control adjustment, load variations, signal variation, environmental conditions, variation in characteristics of the device under consideration and of all other electronic devices in the equipment.

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5.1.1 Device Technology

The technology of a device and its package ***shall*** be identified and understood in sufficient detail to assess the likelihood and consequences of potential failure mechanisms. It is recommended that the device manufacturer be consulted when a device is proposed for use outside manufacturers' specified temperature range.

5.1.2 Compliance with the Electronic Component Management Plan

All devices considered for use in wider temperature ranges ***shall*** be compliant with the equipment manufacturer's ECMP. It is necessary for ECMP requirements to be met only for the temperature range over which the device is specified, since requirements for wider temperatures are provided in this Guide.

Note: IEC PAS Pre-Standard 62239 is recommended as a resource for an ECMP

The use of devices outside the temperature ranges specified by the device manufacturer is discouraged; however, such usage may occur if other options prove to be impossible, unreasonable, or impractical. Justification for such usage may be based on availability, functionality, or other relevant criteria. In no case will such usage result in a design that:

Requires the device to operate at an operating or environmental stress level that significantly increases the risk of catastrophic device failure, loss of equipment function, or unstable operation of the device; or

Requires the device to operate beyond the device's maximum junction temperature or any other limiting temperature, as specified by the device manufacturer, or calculated directly from parameters specified by the device manufacturer.

5.1.3 Alternatives

A review of alternatives ***shall*** be carried out prior to using a device outside the manufacturer's specified temperature range. If an alternative can be shown to be reasonable and practical then it ***shall*** be selected. The results of the evaluation ***shall*** be documented.

Note: Examples of potential alternatives include:

- Using a device specified over the required temperature range, with the identical function, but from a different manufacturer;
- Using a device specified over the required temperature range, with the identical function, but a wider specified temperature range;
- Using a device specified over the required temperature range, with the identical function, but a different package;
- Using a device specified over the required temperature range, that has slightly different specified parameter limits, but which still meets the equipment design goals;
- Using a device with the identical function, but a specified temperature range that still meets the application requirement;
- Using a device specified over the required temperature range, but a different function, and compensating by making changes elsewhere in the equipment design;
- Modifying the device's local operating environment, e.g., adding cooling, etc.;
- Modifying the equipment specified ambient temperature requirement, in co-operation with the customer;
- Modifying the equipment operating or maintenance procedures, in co-operation with the customer; and
- Negotiating with the device manufacturer to provide assurance over the wider temperature range.

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For most applications, the preferred device for use in a wider temperature range should be the one for which the extension beyond the specified range is least.

Note: As an example of this requirement, consider the case in which the required ambient temperature is 92 °C, and no device specified to operate above 85 °C is available. If the two available devices have specified maximum temperatures of 70 °C and 85 °C, then the 85 °C device should, in the absence of other factors, be given preference regarding temperature.

5.2 Device Capability Assessment

5.2.1 Device Package and Internal Construction Capability Assessment

Device qualification test data and other applicable data ***shall*** be analyzed to assure that they support the operation of the device over the end use temperature range and that the package and internal construction type used in device qualification is the same as that to be used in the end application.

Device qualification test data and other applicable data ***shall*** be analyzed to assure that the package and internal construction can withstand the stresses resulting from wider temperature cycling ranges, and that the package materials do not undergo deleterious phase changes or changes in material properties in the wider temperatures.

5.2.2 Risk Assessment (Assembly Level)

A preliminary risk assessment is prudent at this point to help guide decisions regarding the method(s) of capability assessment to be used, as well as how and when they should be applied. Understanding the risks on an application-specific basis enables “risk informed” decision-making and thereby a prediction of the impact of critical decisions.

The process for assessing risks should consider applicable factors associated with the use of devices beyond the manufacturers specified temperature range. Risk factors in this assessment may include:

- Application criticality into which the device will be used.
- Consequences of failure at device, circuit and system level.
- Type or technology of device under consideration.
- Manufacturer data available for the device.
- Quality/reliability monitors employed by the manufacturer.
- Comprehensiveness of production assembly-level screens performed at extended temperature.
- Identification of both managed and unmanaged risks and cost models for each.

Details about the likelihood of occurrence, consequences of occurrence, and acceptable mitigation approaches for each identified risk should be generated. Each risk normally falls into one of the following categories:

- Functionality Risks – Risks for which the consequences of occurrence are loss of equipment, loss of mission, or unacceptable performance. Functionality risks impair the product’s capability to operate to the customer’s specification.
- Producibility Risks – Risks for which the consequences of occurrence are financial impacts (reduction in profitability). Producibility risks determine the probability of successfully manufacturing/fabricating the product (where “successfully” refers to some combination of schedule, manufacturing yield, quantity and other factors).

Several approaches are possible, and each approach constitutes a unique mixture of risk mitigation factors. The results of a preliminary risk assessment should provide insight and assistance to the selection of a viable approach or approaches for establishing the capability of devices being used outside the manufacturer’s specified temperature range.

5.2.2.1 Device Parameter Re-Characterization

Device parameter re-characterization consists of characterising the device parameters over a temperature range beyond that specified by the device manufacturer and, as a result, re-specifying some of the data sheet parameter values or tolerances in the wider temperature range. The device then may be used in applications in which the newly specified parameters provide the required functionality.

If device parameter re-characterization is chosen for capability assessment, then the process described in Annex A ***shall*** be followed.

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If device parameter re-characterization is chosen for capability assessment, it ***shall*** be used in conjunction with a quality assurance process that includes device testing, as described in subclause 5.3.1.

5.2.2.2 Device Stress Balancing

Device stress balancing consists of operating the device at a temperature above that specified by the device manufacturer; and compensating by reducing at least one of the other operating parameters, e.g., power, speed, to the extent that the junction temperature remains below its maximum rating, with acceptable specified margin.

If device stress balancing is chosen for capability assessment, then the process described in Annex B ***shall*** be followed.

5.2.2.3 Device Parameter Conformance Assessment

If device parameter conformance is chosen for capability assessment, then the devices ***shall*** be tested over the entire wider temperature range, according to the process described in Annex C.

Sampling procedures and failure criteria for device testing should be according to Annex C. Where less than 100% are sampled then device testing also ***shall*** include testing at a higher level of assembly over the entire wider temperature range.

5.2.2.4 Higher Assembly Level Testing at Temperature Extremes

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Higher assembly level testing at temperature extremes consists of testing the device over the entire wider temperature range, while the device is incorporated into a higher level of assembly.

If higher assembly level testing is chosen for capability assessment, then the process described in Annex D ***shall*** be followed.

> Note 1: A higher level of assembly may include a module, a printed circuit card, another sub-assembly, or the end item.
>
> Note 2: The intent of subclauses 5.2.2.3 and 5.2.2.4 is to ensure that, if testing is used to assess device capability, then each device is tested at least once over its entire wider operating temperature range. Higher-assembly-level testing results are applicable only to the design revision of the assembly. For other assembly revisions, additional testing or analysis should be performed.

The following steps ***shall*** be followed:

1. Perform a Circuit Element Functional Mode Analysis to determine the device functions / parameters to be tested in order to assure assembly functionality across the target temperature range.
2. Review the assembly level test plan to determine its capability to test the parameters required for successful operation in the assembly. If the test plan is not capable, and cannot be modified to be capable, than this method of uprating is rejected for the application.
3. Conduct the test, analyze the results, and document the conclusions.
4. Insert instructions in the maintenance procedures to require full acceptance test over the target temperature range after every maintenance action that involves replacement of an electronic device, unless the maintenance manual provides adequate alternate procedures. This test should be conducted at an assembly level at which the original capability assessment was done, or higher.

5.2.3 Device Reliability Assurance

Device manufacturers generally qualify devices (including reliability assessment) using the same processes, regardless of the temperature ranges for which they are specified. Generally, they do not represent their products to have a guarantee of lifetime in any application, because they do not know what the use conditions will be. Caution should be exercised when using past experience of the device within the manufacturers specified temperature range to infer reliability outside of the manufacturers specified temperature range.

New and/or accelerated failure mechanisms, which might be evident at the wider temperature range, should be clearly identified and their effects on reliability established.

The following steps ***shall*** be followed:

1. Qualify the devices according the requirements of the user's Electronic Component Management Plan, as specified in 5.1.2 of this document; qualify electrical performance of the devices over the intended range of operating and environmental conditions after a reliability stress conditioning exposure that reflects the life cycle of the application; and determine a margin, supported by analysis using adequate data from the intended application, between the maximum operating junction temperature and the absolute maximum rated junction temperature.
2. The absolute maximum rating of the junction temperature of the device as defined in clause 3 of this document, with a default margin of 20°C should not be exceeded. Other margins may be used if the device user has data to justify them.

   Note: Device reliability can decrease as junction temperature, Tj, approaches maximum. This is a function of time in application at that temperature. If the average Tj of the device is expected to approach maximum in the application, the reliability impact should be addressed. Note also that many avionics applications specify a high temperature environment in which the device is required to operate. The reliability impact on the device is not driven by a thermal condition that is very seldom experienced.

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5.3 Device Quality Assurance in Wider Temperature Ranges

Regardless of the process used to assure device capability, the quality assurance processes documented in the equipment manufacturer's ECMP ***shall*** be applied to the device.

5.3.1 Device Parameter Re-Characterization Testing

If Device Parameter Re-Characterization (5.2.2.1) is used for capability assessment, then the device quality ***shall*** be assured by testing incoming devices according to a defined sampling plan and effective supplier change notice monitoring.

Note: The intent of this guide-line is to monitor the devices to assure that, subsequent to the capability assurance activity, no changes are made in the design or manufacturing processes of the device that will adversely affect its capability in the wider temperature range.

5.3.2 Device Parameter Conformance Testing

If Device Parameter Conformance Assessment (5.2.2.3) or Higher Assembly Level Testing at Temperature Extremes (5.2.2.4) is used for capability assessment, then the device quality ***shall*** be assured through Device Parameter Conformance Testing (this section), Higher Level Assembly Testing (5.3.3) or both, depending on the results of the risk assessment in 5.2.2. See Figure 1 for a flow chart of this process. If this method is used for quality assurance, the device assessment process ***shall*** be done initially by testing all individual devices before use in production equipment or by temperature testing all production equipment at the temperature extremes.

Based on data derived from such testing, testing may be reduced or eliminated by satisfactory test history and by effective supplier change notice monitoring. The sampling rate, confidence limits, and decision criteria ***shall*** be as stated in Annex C.

5.3.3 Higher Level Assembly Testing

If Higher Assembly Level Testing at Temperature Extremes (5.2.2.4) or Device Parameter Conformance Assessment (5.2.2.3) is used for capability assessment, then the device quality ***shall*** be assured through Device Parameter Conformance Testing (5.3.2), Higher Level Assembly Testing (this section), or both, depending on the results of the risk assessment in 5.2.2. See Figure 1 for flow chart showing this process. If this section is chosen for quality assurance, a process similar to that outlined in Annex D ***shall*** be used to determine the capability of the assembly test to validate the uprated device at the target temperature. Assembly level tests are designed to test basic functional performance of an assembly or device. Typically, all functions or “key characteristics” of the end product are typically verified at the sub-assembly or end-item level. The difference between the typical case and the process described here is that the device’s role in these functions, or “key characteristics”, of the assembly are traced, and its capability verified by assembly test over the target temperature range.

5.3.4 Change Monitoring

Device data (such as product change notices or manufacturer data) ***shall*** be monitored to give warning of device changes that may affect the capability of the device to operate over the wider temperature range as established in 5.2.

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5.3.5 Failure Data Collection and Analysis

Failure data should be collected for all uprated devices. When clear trends are evident, the data should be analyzed and corrective action taken.

Failures of devices used in wider temperature range should be analyzed to establish the root cause of the failure.

When failure analysis is conducted, the results ***shall*** be documented.

5.4 Documentation

For each instance of device usage outside the manufacturers specified temperature range, relevant information ***shall*** be documented and stored in a controlled, retrievable format:

The documented information should include:

- Equipment in which the device is used
- Device identification;
- Required operating temperature range;
- Manufacturer-specified operating temperature of the device;
- Alternatives considered and rejected;
- Process for assuring device capability in the wider temperature range (including test and analysis results);
- Process for assuring device quality in the wider temperature range (including test and analysis results);
- Required signatures;