ABSTRACT

Title of the Thesis: COMPONENT SELECTION FOR USE BEYOND MANUFACTURERS' TEMPERATURE SPECIFICATION

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Products in many industries need electronic parts that can operate over wide temperature ranges. Electronic parts may not consistently be rated to meet the application requirements. The uprating process was developed in the late 1990s as a possible method to address this problem. Uprating is a process to assess the ability of a part to meet the functionality and performance requirements of the applications in which the part is used outside the manufacturer's specification range. Uprating is built into the performance assessment step as part of the part selection and management process and requires validation through electrical testing. This process can be resource-intensive in terms of time and money, and it is becoming increasingly so with the increase in part complexity. Therefore, there is a need to preselect parts that have the potential to be uprated. This thesis developed an uprateability assessment process to facilitate

this pre-selection. This process depends on the thermal information provided in recommended operating conditions and absolute maximum ratings.

In this thesis, a quantitative analysis of 140 datasheets is performed to identify the trends in published thermal information for absolute maximum ratings, recommended operating conditions, assembly information, thermal resistances, and temperature dependence of electrical parameters. The analysis identifies the best practices, inconsistencies, and incompleteness in the information provided by the manufacturers. This thesis provides a methodology to establish recommended operating conditions and absolute maximum ratings when unavailable in the datasheets. It outlines the criteria necessary to verify a comprehensive rating section, assigning an information availability level to the thermal ratings to assess the quality of the information provided by the manufacturer, and recommends sources to obtain the missing information.

This thesis also provides an uprateability assessment methodology to identify the components that have the potential to be uprated out of an initial pool of components. The goal is not to uprate all components under consideration but to identify the potential ones that are likely to succeed before they are experimentally evaluated. This process evaluates and eliminates the parts that cannot be uprated, narrowing the potential candidates for uprating and reducing experimental costs.

COMPONENT SELECTION FOR USE BEYOND MANUFACTURERS' TEMPERATURE SPECIFICATIONS

By

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Science
2025

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Acknowledgments

This thesis is a unified endeavor that would not have been possible without the combined efforts and guidance of many individuals, to all of whom I would like to express my gratitude. First and foremost, I sincerely thank my thesis advisor, Dr. Diganta Das, for his invaluable guidance and support throughout my time at the Center for Advanced Life Cycle Engineering and the University of Maryland. His insightful feedback and encouragement have been essential in shaping this thesis.

Secondly, I would like to thank my committee members, Professor Abhijit Dasgupta and Professor Peter Sandborn, for their time as I defended my thesis and for providing feedback as necessary. Thirdly, I would like to thank the faculty in my research group (Professor Michael Pecht, Dr. Michael Osterman, Dr. Michael Azarian, and Dr. Robert Utter) for their valuable insights shared during academic discussions. Their expertise and knowledge have greatly enriched my understanding of the subject matter.

Additionally, I would like to extend my sincere gratitude to the consortium of companies that collaborate with the Center for Advanced Life Cycle Engineering. I am particularly grateful to the individuals in these organizations with whom I had the honor of collaborating. Their patience, approachable nature, and generous willingness to share their expertise have greatly benefited my learning and growth. I am indebted to the staff and personnel at the University of Maryland, and particularly at CALCE, for their cooperation and assistance in providing the necessary resources and facilities for carrying out my research.

I want to express my unwavering love and inexpressible gratitude towards my mother, Anuradha Walvekar. Without her support throughout my life, I would not have been able to achieve all my ambitions. I want to thank my father, Raghavendra Walvekar, for his unwavering support in all my undertakings. I want to thank both my amazing siblings, Akshata and Rohit, especially for taking over all the responsibilities at home while I pursued my Master's. I also want to extend my heartfelt thanks to my uncle Bheemsen Kulkarni for his essential support throughout this journey.

I would also like to thank my partner, Soumik, for being a constant source of encouragement and comfort through this journey. My acknowledgments would be incomplete if I did not mention all the lovely friends who have been vital throughout this time in a place away from home. I want to say a special thanks to Siddharth, Aditya, Aishwarya, Swarup, Sahithi, Ayona, and Soma for their love and support. My sincere apologies to those I’ve inadvertently left out. Without all your support, guidance, and encouragement, this research would not have been possible.

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1. Introduction

Products in many industries require components that work reliably over a wide temperature range, much higher than the widely available "commercial" or "industrial" range. Since the demand was not high enough, the industry faced a shortage of components available for their application [1], as the manufacturers abandoned the non-profitable military markets. Many military standards were canceled in the 1990s, and the use of commercial off-the-shelf (COTS) parts was allowed in military applications. Due to these factors, the industry faced a problem where the rating of certain electronic parts they wanted to use did not match the application requirements [2]. As a response to this problem, CALCE developed a process called "Uprating" that could assess the use of electronic components beyond their rated specifications [3].

Uprating is a "process to assess the capability of a part to meet the functionality and performance requirements of an application in which the part is used outside the manufacturer's specified temperature range [4]." When parts that are needed to continue manufacturing or maintain a product are not available, a "commercial" or "industrial" temperature range part may be considered as a candidate to become a substitute if the part can be determined to meet the functional and performance requirements of the application in which the part is used outside the manufacturer's specified temperature range [5].

The risks associated with using components outside the manufacturers' specifications include [4] die reliability, the capability of the die to operate in the desired environment without physical degradation by mechanisms such as electromigration or oxide breakdown; package reliability, the ability of the packaged component to withstand exposure to the desired environment without failing; and electrical performance, the capability of the component to perform its electronic function in the desired environment. Though the uprating process considers the risks related to the reliability of the components, the focus of this process is to determine if the parts can perform beyond the rated temperature.

The term “uprating” is easy to misinterpret as using the component under unsafe conditions, that is, using it beyond the conditions where it is reliable. Micron’s technical note describes the reliability issues associated with temperature uprating and the risks involved in using components outside the manufacturers’ environmental specifications [6]. It should be noted that the process of “Uprating” is to determine if the part will perform at extended temperatures and not to risk the reliability of the component in consideration. A reliability assessment is required to see if the part will work not only for the time of testing but also over its intended life. If die reliability and package reliability have been ensured by examining the manufacturer’s design process, uprating can be reduced to an issue of electrical performance in the extended temperature range [4].

Uprating was shown to be possible due to the margin between the specified temperature ranges of the parts and the temperatures at which a device can actually work. Such margins exist because of the part manufacturers’ need to obtain a good yield from the manufacturing process, which is subject to fluctuation of material and process parameters [3]. These margins exist as the gap between the recommended operating conditions (ROC) and the absolute maximum ratings (AMR), which are exploited for the process of uprating.

Uprating is built into the performance assessment step as part of the part selection and management process and requires validation through testing. This process can be resource-intensive in terms of time and money, and the process gets difficult with an increase in part complexity. Therefore, there is a need to preselect parts that have the potential to be uprated. This thesis developed an "uprateability process" to achieve this preselection. The goal is not to uprate all components under consideration but to identify the potential ones that are likely to succeed before they are experimentally evaluated. This process will assess and eliminate the parts that cannot be uprated, narrowing the potential candidates for uprating and reducing the cost of the selection process.

2. Thermal Ratings and Their Need

Thermal Ratings are the ratings provided by the manufacturer in the datasheet that define a device's operational and storage temperature limits. In this case, the thermal ratings are limited to recommended operating conditions, and the absolute maximum ratings (Figure 1) are required to assess whether a device suits the intended application. These ratings are usually decided by the manufacturers either by testing the devices themselves and reporting approximate values based on the results, or by following the industry trend for a particular device having the same packaging. The thermal ratings are considered complete if a clear definition of terms and the temperature limits for the operation and storage of the device are provided. All the terms used as part of a rating section (recommended operating conditions or absolute maximum ratings) must be defined by the manufacturer so that the user can interpret them correctly. The temperature limits for complete performance, as well as for the reliability of the device in operation and storage, are required.

The thermal ratings consist of recommended operating conditions and absolute maximum ratings. The recommended operating conditions are "the ratings on the device within which its electrical specifications are guaranteed [7]." The recommended operating conditions include various voltages, temperature ranges, timing parameters, leakage current, and other parameters specific to the component type. These ratings are the conditions recommended by the manufacturer for optimal functionality during operation.

The absolute maximum ratings are "limiting values of operating and environmental conditions applicable to any electronic device of a specified type as defined by its published data, which should not be exceeded under the worst probable conditions [8]." "These values are chosen by the device manufacturer to provide acceptable serviceability of the device, taking no responsibility for equipment variations, environmental variations, and the effects of changes in operating conditions due to variations in the characteristics of the device under consideration and of all other electronic devices in the equipment [8]."

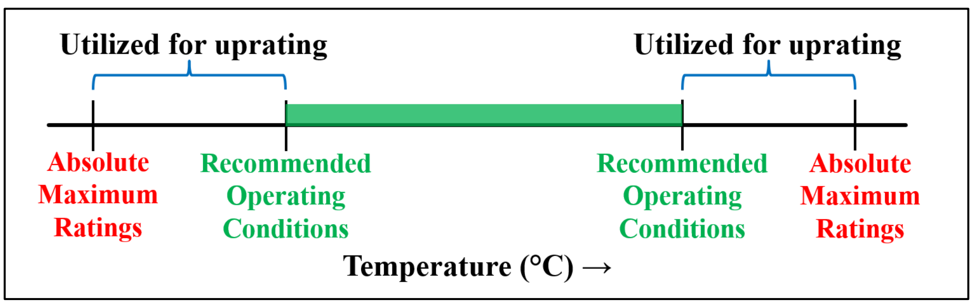

Figure 1: Thermal Ratings

Thermal information is required for several processes in product development. In the part selection and management process, the candidate part goes through performance, reliability, and assembly assessment.

The performance assessment stage of part selection and management assesses the part's "ability to meet the functional requirement [9]" by establishing the operating conditions for the component. One of the first steps in part selection and management is to select candidate parts based on product requirements and constraints. This step includes establishing the product operating temperature range or the target temperature range, reviewing thermal information provided in the datasheet or other technical documentation from the component manufacturer, comparing the component's absolute maximum ratings to the target temperature range, and selecting the candidate parts.

Derating is the practice of improving product reliability by limiting stresses (environmental and operational) to values below its manufacturer-specified limits [9] [10] [11]. Derating reduces the electrical, thermal, and mechanical stress on a component. Thermal information is used to determine the factors that must be considered to operate the component within such temperature limits and establish the reduced temperature limits for the component and a safety margin from the absolute maximum rating for operation.

Uprating is the process of assessing a component's capability to meet functional and performance requirements outside the manufacturer's specified operating conditions [4]. Uprating exploits the difference between the recommended operating conditions and the absolute maximum ratings of a part. For thermal uprating, the temperatures from the absolute maximum ratings and recommended operating conditions are required. Thermal Management relies on data regarding the absolute maximum temperature that must not be exceeded and keeping the component within the recommended temperature range. Thermal management also requires information on estimating the temperature of the device so that a cooling system can be designed around the requirements. This information includes temperature measurement guidelines or references to standards, the thermal resistance values to estimate the junction temperatures, or specific locations on the device at which temperature must be evaluated. This information guides the thermal management process.

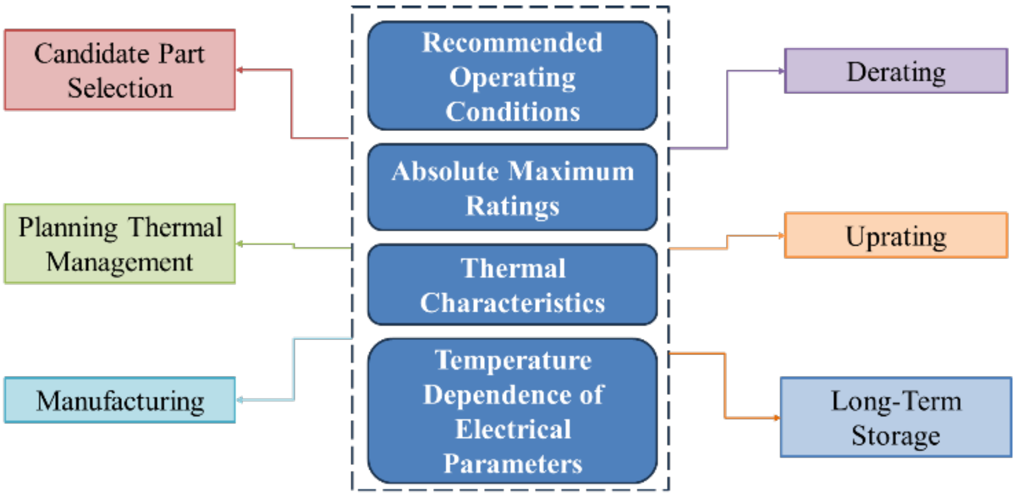

Figure 2: Processes that Require Thermal Information as Inputs

3. Literature Review on Thermal Ratings

Datasheets serve as the users' first source of information for the semiconductor components. A datasheet is a "marketing literature, a technical fact sheet, and a business document, which may include disclaimers and limitations on the use of the part [12]." Sections like the recommended operating conditions, absolute maximum ratings, thermal characteristics, assembly information, and ordering information influence decision-making in part selection and product development.

A review was conducted to identify literature that focuses on what information a user seeks in a datasheet for engineering decision-making and if such information is available. We also sought to find the type and details of the recommendations made. The objective of the literature review is to identify the gaps in desired information and the information provided in the datasheets. The review does not include an assessment of datasheets but of the publications regarding the datasheet, and does not focus on specific part types.

A study was conducted in 2000 by the Center for Advanced Life Cycle Engineering at the University of Maryland that discussed datasheets, their contents, and what they should include [12]. The study examined the sections of the datasheet and their contents. It systematically presented the sections and information in the datasheets, such as the part status, functionality, ratings, electrical specifications, packaging information, ordering information, thermal characteristics, and definitions of the terminology used. It detailed what each section means and how this information is attained. However, it did not present a review of existing datasheets and verify whether the listed sections are provided in the then-available datasheets, which is the objective of our study. The literature is approximately 25 years old and may not reflect the current status, as the electronics industry has undergone many changes since then.

Another study from the Argonne National Laboratory presented a critique of the Wide Band Gap (WBG) datasheets and provided recommendations for specific improvements in datasheet content [13]. The study reported on the commercial Silicon Carbide (SiC) power MOSFET datasheets and "serious discrepancies in key device parameters [13]". It presented the discrepancy in electrical parameter values derived from the datasheet tables, datasheet characteristics curves, and laboratory measurements. It showed that the three methods yielded "three different results with nearly 100% variation [13]." The study showed that users require better and more accurate information from datasheets when using commercial semiconductor parts while designing their systems. It explored the existence of a "large spread in the device parameters during the manufacturing process" and recommended providing a "statistical representation" of the critical device parameters [13]. The study recognized the inconsistencies in the datasheets concerning critical electrical parameters of a SiC MOSFET; however, it focused on the values of specific device parameters. The objective of our research is broader than the values of electrical parameters and includes all thermal information in the datasheet.

A study by a major information system company proposed to create an industry-wide standard for datasheets that depends on an information template obtained from the semiconductor datasheets [14]. It explored developing datasheets in an “industry-approved manner” that is “recognized and imported by an auto-code generation tool.” The objective of the standardization process was to “define standards to collect the data” of a semiconductor device and “store them in an electronic library,” which an “Auto code generator” can then interpret [14]. The process of developing such a tool, based on a datasheet template created from the component specifications, is discussed in the paper. These specifications include the definitions of all “semiconductor electrical parameters” and their “respective variables” [14]. The authors then defined a process to “expand on the standard to include additional new parameters [14].” The standardization process depended on a standardized datasheet, which could be used to draw information. The study, however, relies on a perfect datasheet template, which will assist in faster data collection from a datasheet. Our research will address the importance of having necessary information in the datasheet that helps in a fair comparison among different components.

The review above covers the literature on semiconductor component datasheets and their usage in an application. The reviewed literature has identified the shortcomings of the datasheet specific to their application and provided recommendations regarding how the information should be presented from the user’s point of view. The applications include part selection, product design, and creating software to automate data extraction from the datasheets. Research literature in this focus area is limited; as another possible source of insight, we cover the relevant industry standards.

Many standards developed by the IEC, JEDEC, and the U.S. military provide guidelines on the information that should be included in the datasheets and how to use that information. IEC (International Electrotechnical Commission) is an organization for the “preparation and publication of international standards for all electrical, electronic, and related technologies [15].” The IEC defines a standard as “a document that provides “instructions, guidelines, rules or definitions that are then used to design, manufacture, install, test & certify, maintain and repair electrical and electronic devices and systems [16].” JEDEC (Joint Electron Device Engineering Council) is the technical arm of EIA (Electronics Industries Association), which develops “open standards for the microelectronics industry [17].” Military standards are developed by the U.S. Department of Defense under the Defense Standardization Program (DSP) to “promote standardization of material, facilities, and engineering practices to improve military operational readiness and reduce total ownership costs and acquisition cycle time [18].” These standards, however, were also used by nonmilitary organizations.

The IEC standard 60747-1 provides guidelines for publishing the necessary sections and technical data to aid the user in part usage. The JEDEC standard JESD51-12 provides guidelines for reporting and using electronic package thermal information and serves as a common understanding for communication between the manufacturer and the user. The manufacturers cite the above standards in the datasheets within specific sections to inform the users on how to use and interpret the information.

IEC 60747-1 is an international standard that provides a format for presenting published data in a datasheet [19]. This standard was first published in 1983 and was last revised and updated in 2010. Its primary focus is maintaining consistency and clarifying the information the manufacturers provide in their datasheets and other technical literature. The standard outlines the information that should be included in the technical literature. Some sections listed within IEC 60747-1 relevant to the thermal data are discussed. The IEC standard 60747-1 specifies that manufacturers should include electrical and thermal ratings for the components. Electrical ratings include information such as voltage ratings, current ratings, and power ratings. Thermal ratings include allowable temperature limits essential for understanding component behavior and reliability under different conditions.

Other sections recommended by the IEC standard 60474-1 are the electrical and thermal characteristics and characteristic curves. These characteristics form the basis for understanding the component's behavior and ensuring its reliable operation within specified limits. Users must know the component's electrical characteristics, such as voltage-current relationships, response times, and other performance parameters, to make informed decisions regarding component selection, integration, and designing an effective thermal management system. Additional associated details, such as thermal protection mechanisms and thermal resistance values, help understand the component's behavior under different operating conditions. Graphical representations of characteristics, such as current-voltage curves or frequency response curves and temperature dependence of electrical parameters, provide users with a visual understanding of the component's behavior under varying conditions. These graphs present the maximum and minimum values of a parameter, like the absolute maximum ratings, and how the parameter correlates to another parameter over a range of values. These graphical representations enable users to assess performance, operational limits, and response to electrical and thermal inputs.

JEDEC JESD51-12 is another standard that provides guidelines to manufacturers for reporting electronic package thermal information [20]. The primary goal of this standard is to ensure that electronic package thermal information is reported consistently across different suppliers. JESD51 standards are a collection of various standards defining the methodology for "making meaningful thermal measurements on packages containing single-chip semiconductor devices [20]." The JESD51 standards include several documents (Table I) in addition to JESD51-12, and these documents often need to be utilized together.

Table 1: JESD51 Series of Standards Regarding Thermal Resistance Measurement and Reporting

Standard	**Objective**
JESD51-1	Defines a methodology for measuring junction-to-ambient thermal resistance [21]
JESD51-2A	Specifies guidelines for measuring junction-to-case thermal resistance [22]
JESD51-3	Outlines a low-effective thermal conductivity test board for leaded surface-mount packages [23]
JESD51-5	Extension methods for measuring thermal resistance using a thermal test board [24]
JESD51-7	Use of a thermal test board for measuring the thermal performance of packages [25]

While MIL-STD-883E [26] and MIL-STD-750D [27] provide information regarding thermal resistance measurements, they are stand-alone standards and do not have requirements for a datasheet. Even though some datasheets cite the JESD51-5 and JESD51-7 thermal measurement standards, the information provided in the datasheet does not meet the JESD51-12 standard requirements, which is also a part of the JESD51 standards. Consequently, users face challenges in making informed decisions due to the varying and sometimes ambiguous presentation of thermal information in datasheets.

The part selection and management methodology [9] requires information regarding the components from the datasheets or other technical sources, even if the standards may not always address it. The industry standards may still be insufficient, and an extensive list of content for publishing technical data is necessary.

4. Quantitative Analysis of Datasheet Information

A quantitative analysis of 141 datasheets was conducted to analyze the kind of data available in the datasheets. Given that the uprateability assessment process needs information on recommended operating conditions and absolute maximum ratings, this analysis was conducted to find out what information is available for use by the user. We analyzed recent (release dates of 2015 and later) datasheets of three semiconductor component types, DRAMs (Dynamic Random Access Memory), power switches, and microcontrollers, from their major manufacturers for their thermal information content.

4.1. Research Process

Major manufacturers were identified for each component type (see Figure 3) based on the market share in the automotive application. The top four manufacturers, or those that cover 75% of the market share for a component type, were selected as major manufacturers. However, such a breakdown of data was not available separately for power switches. Hence, the manufacturers for that component type were chosen from a broader umbrella of power electronics, which include Power Discrete, Power Modules, and Power ICs [28]. One hundred and forty-one (141) datasheets were analyzed across these component types (40 DRAMs [29], 50 Power Switches [30] [28] [31], and 51 microcontrollers [32]). These datasheets represent more than 5000 parts as the same datasheet may include parts with variations, such as those in speeds, temperature limits, and package types. The DRAMs covered are DDR3, DDR4, DDR5, and DDR6; their memory ranges from 1 GB to 16 GB. The power switches selected for the analysis are rated at 12V. The microcontrollers/ microprocessors selected are 32-bit and 64-bit devices.

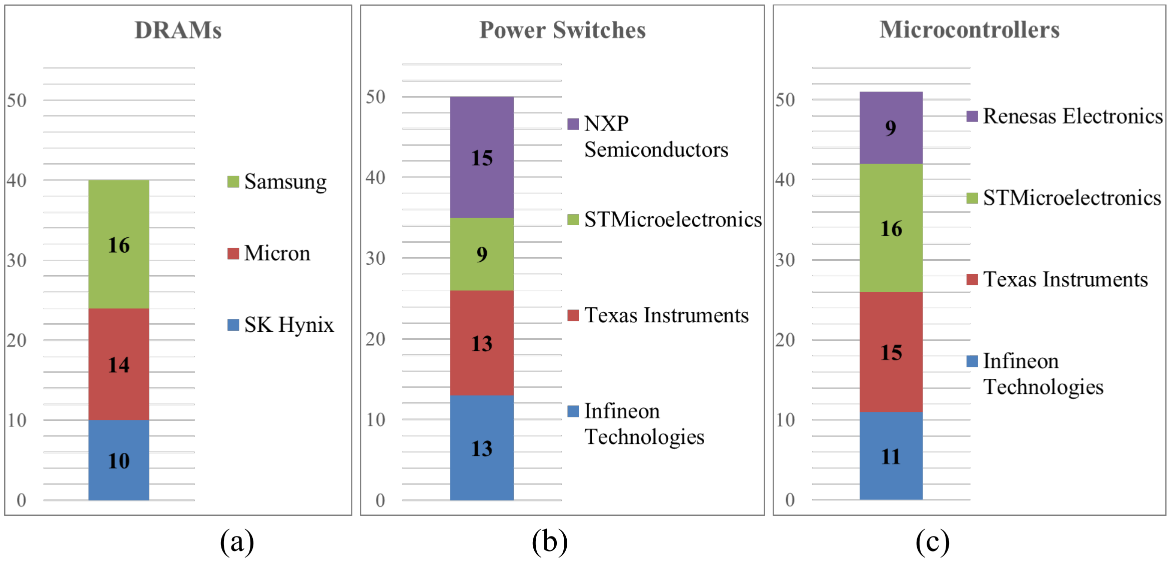

Figure 3: Distribution of the Datasheets Used in the Analysis for (a) DRAMs [29], (b) Power Switches [30] [28] [31], (c) Microcontrollers [32]

The datasheet sections on absolute maximum ratings, recommended operating conditions, thermal characteristics, and assembly information are reviewed. We analyzed the definitions of the terms used, the availability and completeness of rating values, the availability of electrical and thermal characteristic curves, and the availability of assembly information and thermal resistance values. The datasheets are analyzed for compliance with industry standards and the completeness of the information provided. The analysis quantitatively compares the commonalities and variations in providing information across selected component classes. It also identifies the best practices in part datasheets across different commodity types and manufacturers and uses them in developing recommendations. The quantitative analysis is conducted for each criterion, and results are presented according to the information provided for each component class and across the three component classes.

4.2. Results of the Analysis

This section presents a quantitative analysis of the thermal information in the datasheets for absolute maximum ratings, recommended operating conditions, the temperature dependence of electrical parameters, thermal resistances, and thermal information for assembly. In this section, we analyze 141 datasheets to determine the availability and consistency of information in the sections. This section gives a visual representation of the distribution of the datasheets, thermal information in each section, and similarities and variations in the information concerning commodity types.

Table 2 shows examples of temperature ratings provided in the datasheets of the SDRAMs from various manufacturers. The term "absolute maximum ratings" was defined in the IEC standard released in 1961 [8] and remained the same after many revisions. However, none of the analyzed datasheets use the exact definition from the standard and either provide their own definitions (97%) or do not provide a definition at all (3%). The manufacturers that provide their own definitions in the datasheets match the intent of the IEC definition.

Table 2: Examples of Temperature Ratings of SDRAMs

Manufacturer	**Part No.**	**AMR**	**Comments**
Samsung [33]	K4A4G165WB	T_{Stg} = –55°C to 100°C	Maximum case temperature is not mentioned in the AMR.
		T_C = NA*	
Samsung [34]	K4Z80325BC	T_C = NA	The operating temperature range is not provided; only Max T_C and Max T_J are given.
		T_{Stg} = –55°C to 100°C	
Micron [35]	MT40A256M16	T_C = NA	Maximum case temperature is not mentioned in the AMR.
		T_{Stg} = –55°C to 125°C	
SK Hynix [36]	HMA81GR7CJR8N	T_C = NA	Maximum case temperature is not mentioned in the AMR.
		T_{Stg} = –55°C to 100°C	

50% of the total datasheets have only the storage temperature and do not have operating temperature limits in absolute maximum ratings (see Figure 4). The user requires both storage temperature and operating temperature in AMR. Therefore, this analysis shows the number of datasheets with both the temperatures and the number of datasheets that provide only storage temperature.

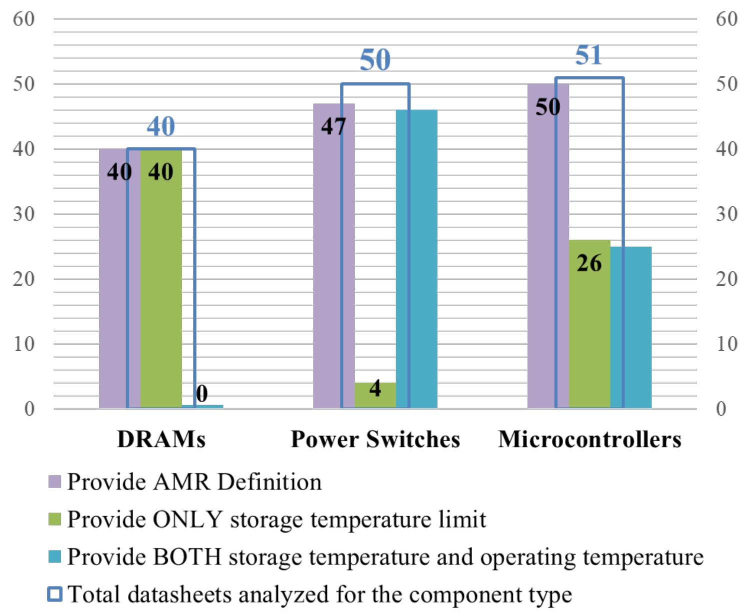

Figure 4: Information in Absolute Maximum Ratings

In 28% of the datasheets analyzed, manufacturers do not provide a recommended operating conditions section (Figure 6). All DRAM datasheets have a dedicated "operating conditions" section and an absolute maximum ratings section. However, 48% of the datasheets for power switches have operating temperatures defined only in the absolute maximum ratings section and do not have a recommended operating temperature. Some microcontroller datasheets have a separate recommended operating conditions section, but they only define the electrical parameters in that section and do not include operating temperatures.

Another observation was related to the variation in the title used for the recommended operating conditions. Some manufacturers do not use the term recommended operating conditions in their datasheets; instead, they use terms like "functional range," "component operating temperature range," or "operating conditions," as shown in Table 3. Only 22 datasheets used the term “Recommended Operating Condition” to describe the operating conditions for the component, as shown in Figure 5.

Table 3: Variations in Operating Conditions Terminology

Datasheet	Terminology
Micron DRAM [37], Samsung DRAM [38]	Component Operating Temperature Range
Infineon Power Switch [39]	Functional Range
NXP Power Switch [40]	Thermal Ratings
Infineon Microcontroller [41]	Operating Conditions

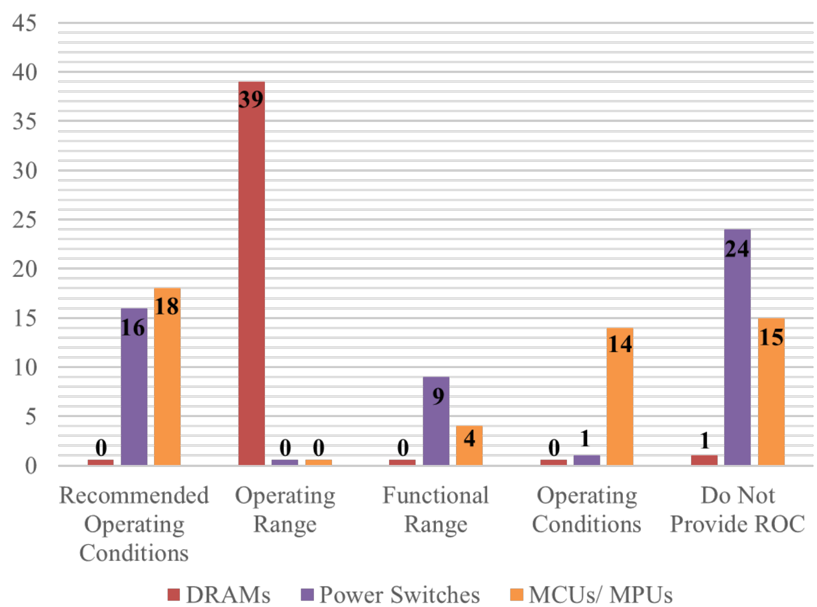

Figure 5: Variations in section titles for operating conditions

Using a term different from the recommended operating conditions to provide the operating conditions of the component is acceptable if the manufacturer defines the terms and does not leave it up to the interpretation of the user. However, 52% of the datasheets with an operating conditions section do not define the term used or have a definition that does not match the intent of the IEC definition (Figure 6).

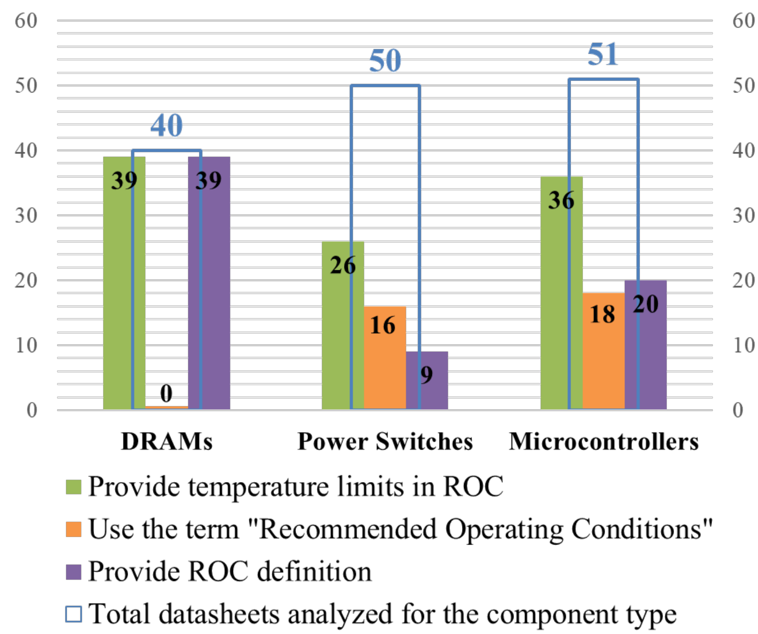

Figure 6: Information in Recommended Operating Conditions

Manufacturers across the industry tend to agree on the temperature locations for a particular component type. For example, for DRAM components, the manufacturers provide ratings in terms of case temperature [42] [35] [43] in the datasheets, while for power switches, the ratings are provided in terms of junction temperature [44] [45] [46]. However, if the temperature stated in the ratings is not defined clearly in the datasheets, it is difficult for the users to estimate these temperatures. For ambient temperature, there can be multiple conditions, such as free convection and forced convection, measured at a certain distance from the component or measured with a heat sink. The datasheet for the TC212 Infineon Microcontroller [41] provides the ambient temperature as part of the ratings in the recommended operating conditions section. However, ambient temperature is not defined in the datasheet, nor has any document been referenced that defines this term.

In the Samsung K4A4G165WE SDRAM datasheet, the ratings are provided as case temperatures and have been defined in the datasheet as shown in Figure 7. Also, in the following note, it has been clarified what case temperature means and its location. In 72% of the datasheets analyzed, manufacturers do not define the temperature notation or state at which location on the component to estimate these temperatures during operation.

Symbol	Parameter		rating	Unit
T_{OPER}	Operating Temperature Range	Normal	0 to 95	°C
		Industrial	-40 to 95	°C

NOTE :
1. Operating Temperature T_{OPER} is the case surface temperature on the center/top side of the DRAM.

Figure 7: Operating Conditions – Definition of the terms used [40]

Inconsistencies were observed in providing data for the estimation of temperatures. The ambient temperature is not defined for microcontrollers, while the case temperatures are defined for the DRAM components. However, 100% of the datasheets reviewed cited the JEDEC standards JESD51-5 and JESD51-7, even without providing the thermal resistance values. When ratings are specified in terms of ambient temperature, it is possible to calculate it using the thermal resistance between the junction and the ambient.

The temperature dependence of electrical parameters represents how the electrical parameters behave with temperature changes. Also, 50% of the datasheets for power switches have characteristic curves that define the temperature dependence of electrical parameters, as shown in Figure 8. The DRAMs have another kind of information that provides different refresh rates as discrete data points for increasing temperature.

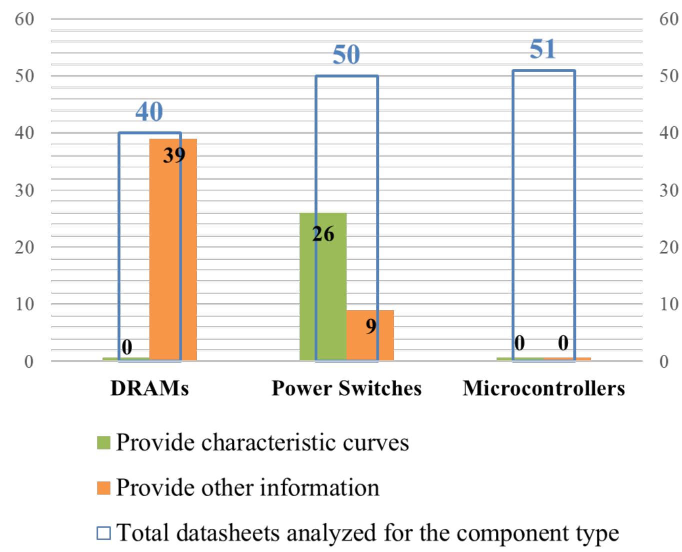

Figure 8: Information Regarding Thermal Characteristics

Thermal resistance (denoted as θ in this paper) is defined as a "measure of the steady-state heat flow from a point of higher temperature to a point of lower temperature, calculated by dividing the temperature difference by the power dissipated between the two points [21] [47]." 38% of the datasheets (see Figure 10) for DRAMs provide thermal resistance values, while 96% of the datasheets for power switches and 90% of the datasheets for microcontrollers give this information. In the following list of thermal resistance types, the first letter in the subscript denotes the point of higher temperature, and the second letter refers to the point of lower temperature. The different thermal resistances that may be available in the datasheets are junction-to-ambient (θ_{JA}), junction-to-lead (θ_{JL}), junction-to-case (θ_{JC}), junction-to-board (θ_{JB}), and case-to-ambient (θ_{CA}), and are shown in Figure 9. Some datasheets provide thermal resistances for different air flow rates. Having multiple thermal resistances is beneficial to the user and is considered the best practice since the user may have access to different areas of the component or the system to perform temperature measurements and control the thermal behavior.

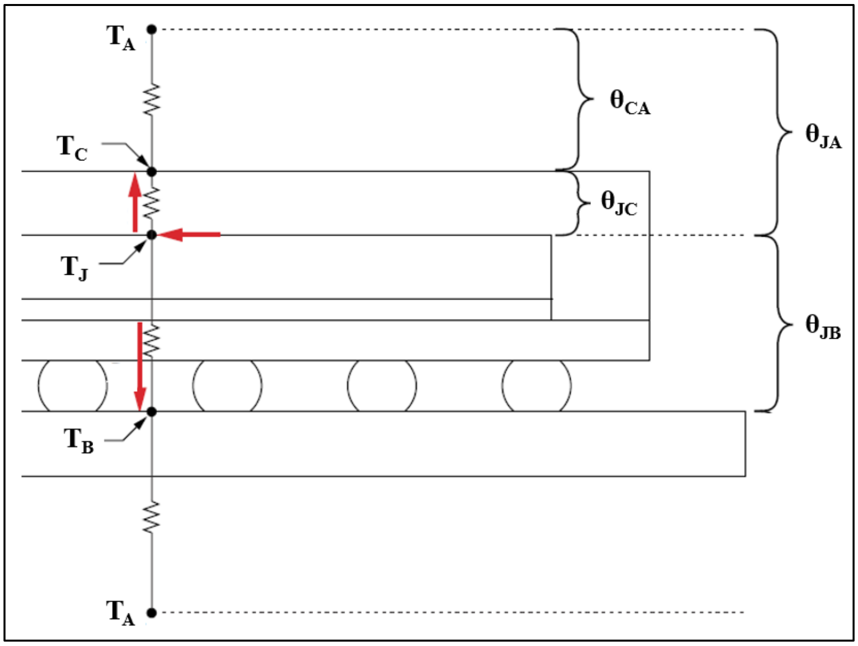

Figure 9: Thermal Resistance Locations [42]

Another thermal parameter is the thermal characterization parameter Ψ (Psi), which can be defined for junction to board and junction to the top of the case. The thermal characterization parameter Ψ_{JB} is the difference between the junction temperature and the temperature of the board measured at the top surface of the board per unit power [22]. The thermal characterization parameter Ψ_{JT} represents the difference between junction temperature and the temperature at the top center of the outside surface of the component per unit power [22]. The experimental configuration to characterize Ψ represents the application environment better than the θ values [48]. Users can apply the Ψ equations [22] for thermal management planning [49].

Among the DRAM manufacturers, only Micron provided thermal resistance values (see Figure 10). The most common thermal resistance value across all the datasheets is junction-case (θ_{JC}) (68% of the total datasheets). The most common thermal resistance type in the datasheets for power switches and microcontrollers is junction-ambient (θ_{JA}) (93%). The datasheets from

Texas Instruments and ST Microelectronics are the most consistent in providing both θ (100%) and Ψ values (75%).

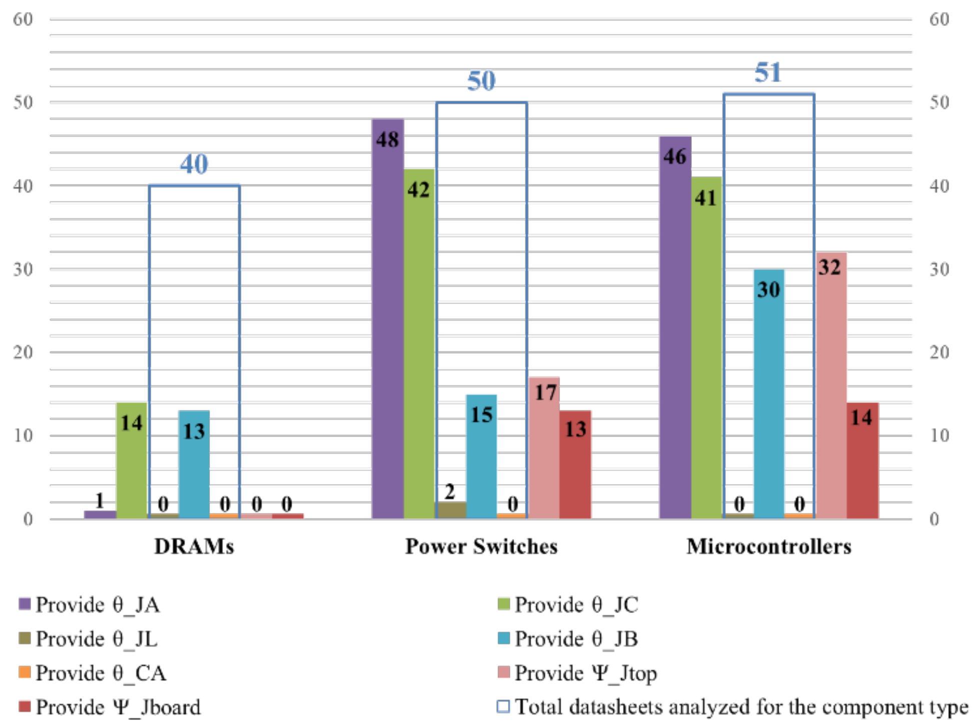

Figure 10: Information Regarding Thermal Resistances

Thermal information for assembly includes soldering temperature, soldering profile, and moisture sensitivity level (MSL). Having information regarding the assembly in the datasheets is considered best practice. However, sometimes, this information is provided in other documents. Lead temperature or soldering temperature is the maximum allowable temperature at a specified position on the leads of a part during the soldering process. A soldering profile is a "graphical portrayal of temperature experienced by an assembly as it passes through a soldering process [50]." For pre-assembly handling, information regarding the moisture sensitivity level (MSL) is provided, which is defined as a "rating indicating a device's susceptibility to damage due to absorbed moisture when subjected to reflow soldering [51]." The MSL rating of a component "determines its floor life before board mounting after the dry-pack packing has been opened [52]."

None of the datasheets for DRAMs have any information regarding the assembly of the component (see Fig. 10). About 50% of the datasheets for power switches provide the moisture sensitivity level, and 40% have assembly guidance in the datasheet. Approximately 60% of the datasheets for microcontrollers provide information regarding assembly, including reference to the soldering profile as per standards like JESD-020D [51]. Some datasheets for microcontrollers cite the AEC-Q100 [53] and JESD020 [51] standards for soldering profiles. However, these standards do not provide a solder profile, making this information incomplete, as shown in Figure 11.

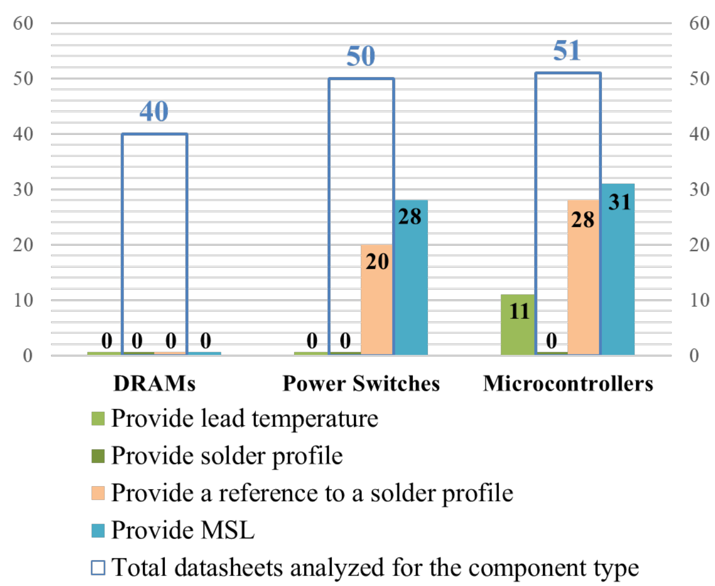

Figure 11: Thermal Information Regarding Assembly

4.3. Conclusions Concerning Uprateability Assessment

This analysis shows that thermal information is inconsistent and sometimes incomplete across different manufacturers and commodity types. Some examples include the definition of the absolute maximum ratings not following the IEC standard and the absolute maximum ratings not containing the operating temperature. Only the storage temperature is not helpful in analyzing the maximum limits on the component during operation. There is also ambiguity in interpreting the information in the recommended operating conditions due to the variation in terminology and lack of proper definitions. The temperature notations used in recommended operating conditions and absolute maximum ratings do not always have a definition, creating ambiguity in the interpretation of the temperature estimation location. Information regarding thermal resistances and temperature dependence of electrical parameters is missing from some datasheets.

5. Comparison of Datasheet Information from the Late 1990s to the Recent Datasheets

In addition to the analysis of these post-2015 datasheets, comparisons were made for information content with sample DRAM datasheets from the late 1990s and early 2000s for Micron and SK Hynix. There have been technological changes between the two periods, and the same class of components was compared to the greatest extent possible. There are variations in the datasheets among commodity types and manufacturers. We reviewed whether there is any pattern of change between these two periods for a commodity type.

In some datasheets from the late 1990s and early 2000s, the recommended operating conditions were not a separate section but a subsection of the absolute maximum ratings (see Figure 12). Also, the operating conditions for the DRAMs are provided in terms of ambient temperature and not the case temperature [54] [55], as highlighted.

Absolute Maximum Ratings

Stresses greater than those listed may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

Voltage on VDD Supply
Relative to VSS .... -1V to +4.6V
Voltage on Inputs, NC or I/O Pins
Relative to VSS .... -1V to +4.6V

Operating Temperature
T_{OPR} (Commercial - ambient) ...... 0°C to +65°C
Storage Temperature (plastic) ...... -55°C to +150°C

Figure 12: Absolute maximum ratings for a 2004 Micron Synchronous DRAM Module [55]

There is a change in verbiage in those sections provided by the manufacturers between the older datasheets and those from 2015 onwards; for example, the recommended operating conditions sections in the recent datasheets have different terminologies for the temperature ranges, and the terminology varies among manufacturers (see Table 4). Most datasheets from 2015 onwards provide only the storage temperature as part of the absolute maximum ratings. The case temperatures are provided only as part of the operating conditions, and a maximum operating temperature limit is not mentioned in the absolute maximum ratings. Manufacturers also offer data about the other operating conditions for the extended temperature range (e.g., commercial, industrial, automotive), which was not the case with the earlier datasheets.

Table 4: Temperature Range Identifiers for various DRAM Manufacturers for datasheets from 2015 onwards

Manufacturer	Temperature Ranges and Their Identifiers
Samsung	Normal (0°C to 95°C) Extended (-40°C to 95°C)
Micron	Commercial (0°C to 95°C) Industrial (-40°C to 95°C) Automotive (-40°C to 105°C) Ultra-High (-40°C to 125°C)
SK Hynix	Normal (0°C to 95°C) Extended (-40°C to 95°C)
Apacer Technologies	Normal (0°C to 95°C) Extended (-40°C to 95°C)

There was some commonality across all parts of the identifiers (commercial, industrial, automotive, and military), and the temperature ranges were defined uniformly for each identifier. In recent datasheets, users can no longer assume the temperature range according to the terminology due to the varying terminology. Manufacturers define their temperature ranges, and there is no longer a standard terminology that is followed across the industry. The term "industrial" may have different temperature values for various manufacturers.

In conclusion, some differences are observed when comparing the older and recent datasheets. The absolute maximum ratings section in the older datasheets contains both the storage and operating temperatures. The older datasheets also do not use the term "recommended" to describe the operating conditions. Not every manufacturer uses the term "recommended" operating conditions for temperature ratings, while they use it for DC ratings. However, the recent datasheets clearly define the recommended operating conditions section. All these observations are factored in the required thermal information, incorporating best practices from the past, even if they are no longer in use.

6. Necessary Thermal Information in a Datasheet

The analysis in the previous sections shows that there are variations in the thermal information provided in the datasheet across manufacturers and commodity types. Inconsistent and incomplete information can affect decision-making regarding the use of components. Based on the findings, we list the thermal information that the users require. These contents can be used as guidelines by the manufacturers to improve thermal information in the datasheets. The contents can also be adopted as standards to guide the manufacturers in providing appropriate information to the users. The recommendations are made for the required sections in the datasheets, information in the absolute maximum ratings and recommended operating conditions sections, the temperature notations used in the datasheets, and other thermal information, including thermal characteristics and assembly guidelines.

6.1. Standard Section in the Datasheets

One of the findings of the analysis was the missing sections in the datasheets and the missing information in the sections. Three sections on thermal data should be provided in the datasheets, and information should be provided regarding the component's specification, operational limits, and thermal characteristics. This section presents a template section with pointers to the information that should be included in each section. The users can use this template to interpret the thermal information from the datasheets and establish whether they have the complete information.

Absolute Maximum Ratings

Absolute maximum ratings are limiting values of operating and environmental conditions applicable to any electronic device of a specified type as defined by its published data, which should not be exceeded under the worst probable conditions [8]. The absolute maximum rating indicates the thermal limits beyond which the component should not be operated to avoid permanent damage or failure. The thermal ratings should refer to the operating and storage conditions. Another useful temperature would be one that defines the temperature range for a component in its "nonoperating lifetime [56]." The nonoperating lifetime is defined as "the length of time that a component is not operating in an application [56]." Though the temperature range for nonoperating lifetime is not present in the absolute maximum ratings section, the user may find this information useful in making design decisions. An ideal section of absolute maximum rating would follow the pattern in Table 5, including the notes.

Table 5: Absolute Maximum Ratings – Content

Thermal Parameter	Values	
	Min	Max
Storage Temperature (T_{Stg})		
Operating Temperature (T_A, T_C or T_J) (2) *		

Notes: (1) Absolute Maximum Rating: Definition as per the IEC 62240 or with the same intent or a reference to a definition

(2) T_A, T_C, or T_J: Definition

*The operating temperature can be expressed in terms of ambient (T_A), case (T_C), or junction (T_J).

Recommended Operating Conditions

Recommended operating conditions are the ratings on a device within which its electrical specifications are guaranteed [7]. The information from this section provides operating conditions for the component within safe and reliable thermal limits while exploiting the full electrical specifications. The ideal section on recommended operating conditions should follow the pattern in Table 6, including the notes.

Table 6: Recommended Operating Conditions – Content

Thermal Parameter	Operating Temperature (3)*	
	Min	Max
Temperature Range 1 (2)		
Temperature Range 2…		

Notes: (1) Recommended operating conditions: Definition as per the IEC Standard 62240

(2) Temperature ranges, if defined by the manufacturer (e.g., Normal, Industrial, Automotive)

(3) T_A, T_C, or T_J: Definition

*The temperature can be expressed in terms of ambient (T_A), case (T_C), or junction (T_J).

6.2. Temperature Notation and Estimation

The temperature notation used in the datasheets is the ambient temperature (T_A), case temperature (T_C), junction temperature (T_J), and storage temperature (T_{Stg}). Ambient Temperature is defined as "the temperature of the specified surrounding medium (such as air, nitrogen, or a liquid) that comes into contact with a semiconductor device being tested for thermal resistance [57]." Junction Temperature is defined as "the temperature of the semiconductor junction in which a major part of the heat is generated. The measured junction temperature is indicative only of the temperature near the element used to measure the temperature [57]." Case Temperature is defined as "the temperature at a specified, accessible reference point on the package in which a semiconductor die is mounted [57]." These definitions are from the JEDEC standard but are not used in the datasheets. Based on these considerations, the following recommendations are put forth to the manufacturers and the standard-making bodies.

Definition of temperatures used in the data sheets

The temperature notation used in the data sheets must be defined. The user should be able to interpret the data from the datasheets according to the definitions provided by the manufacturer. If the manufacturer does not wish to give the definitions, then a recognized industry standard must be referenced within the datasheet that contains such necessary information. Such definitions (or references to them) ensure that users can accurately understand and apply temperature ratings, facilitating proper component selection and reliable system design. Standardized definitions or references help eliminate ambiguity, promoting consistency in interpreting thermal specifications and enhancing the quality and reliability of electronic products.

The definition of the temperature used in the datasheet must include the temperature notation (i.e., case, ambient, junction, storage), entity of estimation (medium surrounding the component, package, die), and the location of the point of estimation. The temperature notation distinction is vital as different types of temperatures represent different operating conditions and thermal behaviors of the component. The entity of estimation refers to the object or substance for which we are measuring the temperature. The location of the point of estimation indicates the precise location of the component or the proximity from the component where the temperature should be estimated. Such location(s) could be the surface of the component, a specific distance from a reference point on the package, or any other designated location. Knowing the location of estimation is critical as it affects the accuracy of temperature measurements and allows users to apply proper thermal management strategies.

Estimation of temperatures used in the data sheets

An unambiguous description of how to estimate temperatures during operation for an application should be provided in the datasheets along with the ratings. When ratings are specified in terms of ambient temperature, it is crucial to identify which ambient temperature is being referred to – the temperature of the air surrounding the entire product, the temperature at the fan inlet, or the temperature around the specific component. Additionally, clear guidance should be provided regarding the distance from the surface of the component at which this ambient temperature should be estimated. Understanding this distance is crucial as it can significantly impact the actual operating conditions experienced by the component.

6.3. Assembly information

Information like the lead temperature or solder temperature, solder profile, and moisture sensitivity level is necessary for assembly assessment. While having this information in the datasheets is considered a good practice, and some manufacturers provide it, we have observed that this information is also provided in separate technical documents. The best practice followed by a manufacturer is to provide a soldering profile for the component assembly in a datasheet. However, in some cases, the soldering profile is provided in a separate document. It is necessary to provide information regarding minimum and maximum soak temperatures, soak times, ramp-up rates, peak temperature, and peak package body temperature (see Figure 13).

For pre-assembly handling information, the moisture sensitivity level (MSL) is provided. The MSL rating can assist the user in handling the components so that they can be "properly packaged, stored, and handled to avoid damage during assembly, solder reflow, attachment, and/or repair operations [51]."

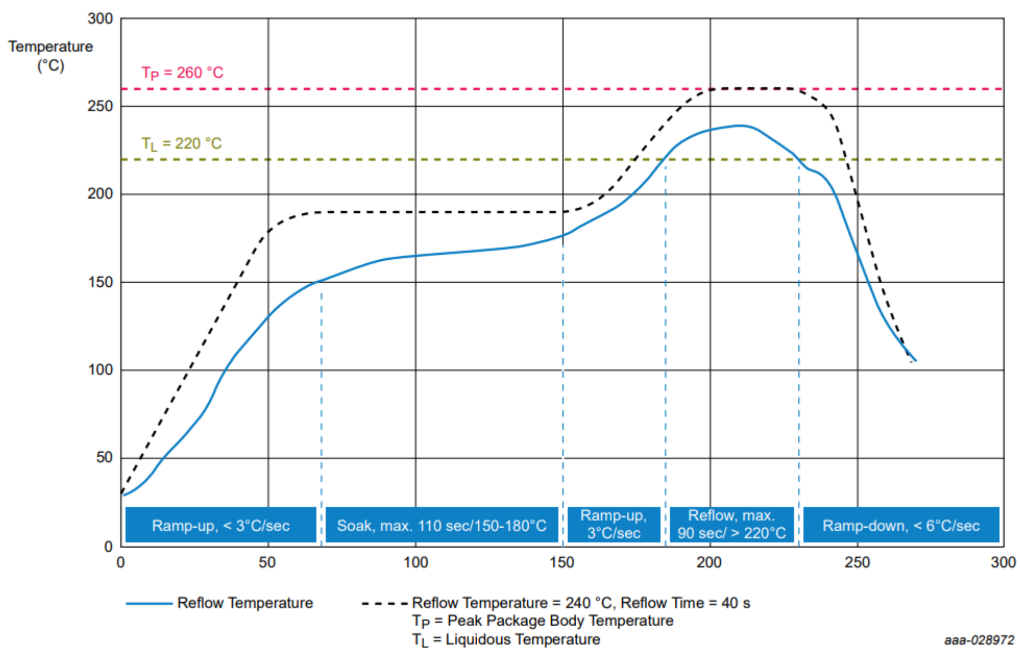

Figure 13: The solder profile for the 06XS4200 High-side power switch [58] is provided by NXP Semiconductors in a reference document [59]

7. Establishing Recommended Operating Conditions and Absolute Maximum Ratings

From the information in Section 4, we conclude that all the information necessary to perform an uprateability assessment is not provided in the datasheets. We need complete information on recommended operating conditions and absolute maximum ratings. Recommended operating conditions are "the ratings on a device within which its electrical specifications are guaranteed [7]." Ratings may be given in several ways by the manufacturers. There is uncertainty regarding what a manufacturer believes must be included in the ratings. If the manufacturer does not offer ratings that meet the IEC standards, the user can determine whether they have all the information required to decide on part selection by analyzing and interpreting the information from the datasheet. The user requires three key points to have complete information on recommended operating conditions:

- whether the manufacturer guarantees electrical specifications,
- the minimum and maximum values for each temperature range,
- the operational restrictions, if any exist, should be specified.

Absolute maximum ratings are "limiting values of operating and environmental conditions applicable to any electronic device of a specified type as defined by its published data, which should not be exceeded under the worst probable conditions [8]." When the absolute maximum is not clearly stated in the datasheets, the user requires three key pieces of information to confirm if a temperature range is the absolute maximum rating:

- the maximum and minimum values for the operating temperature parameter,
- the maximum and minimum values for the storage temperature parameter and
- the possibility of damage and reliability concerns beyond the AMR.

When the thermal ratings are not defined clearly in the datasheets or any other technical literature by the manufacturer, the user needs to establish these ratings using their best engineering judgment. The user can establish the thermal ratings in different ways.

- The user can establish the initial part ratings through the interpretation of the available information in technical literature, like the datasheets, application notes, qualification reports, and derating guidelines. The information can also be established by conducting a similarity analysis with respect to other comparable parts related to the part under consideration. The similarity may be based on package type, material, power dissipation, and functionality.
- The user can request or confirm the thermal ratings for a part through communication with the part manufacturer, the distributor, or the contract manufacturer. The thermal ratings document for manufacturer communication is provided in **Appendix A: Thermal Ratings Document**.

The user may perform testing to determine the range over which the part can be used. Still, the test does not provide the recommended operating conditions that the manufacturer intends and within which the manufacturer guarantees full specifications. Testing a component may be helpful to determine whether the part is suitable for an application. Still, a test might not give the values for the recommended operating conditions and the absolute maximum ratings. Testing is also not useful as an industry solution, as it requires time and effort. Users need to test their components to assess the operation, and testing the component only for establishing ratings is not practical.

7.1. Assigning Information Availability Levels to the Ratings

To utilize the information about the component, it's essential first to evaluate the quality of the existing information and establish its trustworthiness. We introduce a new term, "information availability level (IA)," to quantify the quality of the information. The information availability level is used to assess how confident the user should be in using the information provided by the manufacturer. The information availability level is essential to identify the gaps between the user's requirements and the information available in the datasheet. It provides insight into identifying the sources from which the missing information in the datasheet can be obtained.

The information is assessed as per the requirement for the recommended operating conditions and absolute maximum ratings using four constituents, as shown in Table 7. An information availability level is then assigned to each scenario within a constituent based on clarity and confirmation (of information by the part manufacturer). The information availability level is designated as a combination of each constituent's information availability.

7.1.1. Constituents of Information Availability

Constituent groups are the information a user looks for in the datasheets for recommended operating conditions and absolute maximum ratings. There are four constituent groups for absolute maximum ratings and three constituent groups for recommended operating conditions, as shown in Table 7.

Table 7: Constituents of Information Availability

Type of Rating	Constituent	Description	Comments
Absolute Maximum Ratings	A	Definition of the rating title	The definition should clarify the possibility of damage and reliability concerns beyond the AMR.

Type of Rating	Constituent	Description	Comments
	B	Storage temperature values	Maximum and minimum temperature values allowed for storage.
	C	Operating temperature values	Maximum and minimum temperature values allowed for operation.
	D	Definition of the temperatures used	The temperature(s) provided in the section (case, junction, ambient) should be defined in the notes.
Recommended Operating Conditions	E	Availability	If a section on operating temperature limits is available and titled “Recommended operating conditions”
	F	Definition of the rating title	If the manufacturer uses any term other than recommended operating conditions or if the manufacturer has a different definition of recommended operating conditions. The definition should state if full electrical specifications are guaranteed within ROC.
	G	Temperature range values	The minimum and maximum temperature values.

Constituent D (Definition of the temperatures used) can be provided anywhere in the datasheet. However, these definitions are necessary to interpret any temperature ratings. It has been considered as part of AMR assessment since, in most datasheets, the AMR section appears before the ROC section. Each constituent is associated with four possible scenarios. The available information can be assessed for availability, completeness, and consistency using the information availability metric.

7.1.2. Information Availability Metric

An information availability number is assigned based on the criteria shown in Table 8. The scenario is recorded for each constituent, and the information availability numbers are assigned accordingly. It quantifies the level of information that is currently available to the user as information availability levels. It compares the information from the datasheet or other sources to the user requirements of the thermal ratings for recommended operating conditions and absolute maximum ratings, and based on this comparison, the information availability number is assigned.

Table 8: Information Availability Levels

Assigned Number	Significance	Description	Information Availability Level
1	Information is not available.	Information is unavailable to the user. The manufacturer needs to be contacted.	**Low**
2	Information is available, but it is inconsistent with industry standards.	Information does not comply with industry standards and is difficult to interpret. Such information must be interpreted and confirmed with the manufacturer.	**Moderate-Low**
3	Information is available and matches the intent of the industry standards.	The manufacturer has a different format for providing complete data. Such information does not need to be confirmed by the manufacturer.	**Moderate-High**
4	Information is available.	Information is consistent with the standards.	**High**

The information availability level for every constituent (A-G in Table 1) is evaluated using this metric, and the overall information availability level is assigned to the combination of these constituents. Each constituent is assigned an information availability level as ‘high’, ‘moderate-high’, ‘moderate-low’, or ‘low’. The overall information availability level is decided by a combination of the information availability levels of each constituent and assigned independently for recommended operating conditions and absolute maximum ratings.

Each constituent for recommended operating conditions and absolute maximum ratings is assigned weights based on the importance to the user. These weights can be decided by consulting industry experts, conducting surveys among multiple users, or using multicriteria decision-making techniques. These decisions will depend on various factors, including the user's knowledge of a particular manufacturer and prioritizing the information crucial to the application. For example, some users may find temperature limits more important than the definition of the term used to provide recommended operating conditions. Such responses can be recorded using surveys, and weights can be assigned by averaging these responses. In this paper, the analytical hierarchy process [60] is used to assign weights. This process, however, is also subjective and is presented as an example.

This process follows a pairwise comparison, which applies the principle of comparative judgments [61]. The comparison gives "the relative importance of elements" at the constituent level "to the shared criteria" in the information availability level [61]." AHP quantifies the "relative importance of each criterion and alternative, ultimately providing a numerical ranking that reflects the decision-maker's preferences and priorities [62]." The constituents are compared by providing "linguistic (semantic) evaluations of mutual importance [63]" in relation to the information availability level using a basic scale shown in Table 8 and written in a matrix form.

Table 9: Saaty's relative importance scale [64]

Definition	**Numerical Value**
Absolute dominance of the element i over the element j	9
Very strong dominance of the element i over the element j	7
Strong dominance of the element i over the element j	5
Weak dominance of the element i over the element j	3
The same importance of the elements i and j	1
Weak dominance of the element j over the element i	1/3
Strong dominance of the element j over the element i	1/5
Very strong dominance of the element j over the element i	1/7
Absolute dominance of the element j over the element i	1/9
(Intervalues)	(2,4,6,8)

Table 9 gives the values for pairwise comparison based on Saaty's relative importance scale. The matrix is "symmetrical in relation to the main diagonal [63]." In other words, the elements in the upper triangle of the matrix are reciprocals of the elements in the lower triangle. Additionally, the elements on the main diagonal are equal to 1 ($a_{ij} = \frac{1}{a_{ij}}; a_{ii} = 1$).

Table 10: Pairwise Comparison Matrix for Constituents of Information Availability for AMR

Constituent	**Definition**	**Storage Temperature**	**Operating Temperature**	**Definition of the Temperatures Used**
Definition	1	2	1	1
Storage Temperature	½	1	¼	¼
Operating Temperature	1	4	1	1
Definition of the Temperatures Used	1	4	1	1
Column Totals	3.5	11	3.25	3.25

The most used "optimization methods of prioritization are the eigenvalue method, the logarithmic least squares method, and the method of additive normalization [63]." Due to its simplicity and frequent use, the method of additive normalization is used in this study. To obtain the weights for the constituents, each element from the given column of the pairwise comparison matrix is divided by the sum of the elements of this column (normalization). The elements in each row are then summed up, and the resulting sum is divided by the rank of the pairwise comparison matrix Table 11.

Table 11: Normalized Matrix to Determine Weights for the Constituents of AMR

Constituent	Definition	Storage Temperature	Operating Temperature	Definition of the Temperatures Used	Row Totals	Averages
Definition	0.28571	0.18182	0.30769	0.30769	1.0829	0.27
Storage temperature	0.14286	0.09091	0.07692	0.07692	0.3876	0.1
Operating temperature	0.28571	0.36364	0.30769	0.30769	1.2647	0.32
Definition of the temperatures used	0.28571	0.36364	0.30769	0.30769	1.2647	0.32

The process is repeated for recommended operating conditions. The pairwise comparison matrix of the constituents is provided in Table 11 and the normalized matrix in Table 12.

Table 12: Pairwise Comparison Matrix for Constituents of Information Availability for ROC

Constituent	Availability	Definition of the Rating Title	Temperature Range Values
Availability	1	1	½
Definition of the Rating Title	1	1	½
Temperature Range Values	2	2	1
Column Totals	4	4	2

Table 13: Normalized Matrix to Determine Weights for the Constituents of ROC

Constituent	Availability	Definition of the Rating Title	Temperature Range Values	Row Totals	Averages
Availability	0.25000	0.25000	0.25000	0.7500	0.25
Definition of the Rating Title	0.25000	0.25000	0.25000	0.7500	0.25
Temperature Range Values	0.50000	0.50000	0.50000	1.5000	0.50

The weights determined by the analytical hierarchy process are summarized in Table 14.

Table 14: Weights for the Information Availability Level for Each Constituent

Type of Rating	**Constituent (IA_i)**	**Description**	**Weight (w_i)**
Absolute Maximum Ratings	A	Definition of the rating title	0.3
	B	Storage temperature values	0.1
	C	Operating temperature values	0.3
	D	Definition of the temperatures used	0.3
Recommended Operating Conditions	E	Availability	0.25
	F	Definition of the rating title	0.25
	G	Temperature range values	0.5

Then, the information availability level for recommended operating conditions and absolute maximum ratings can be calculated using weighted averages, as shown by equations 1 and 2.

$$IA_{AMR} = (IA_A \times w_A) + (IA_B \times w_B) + (IA_C \times w_C) + (IA_D \times w_D) \quad \textit{... Equation 1}$$

$$IA_{ROC} = (IA_E \times w_E) + (IA_F \times w_F) + (IA_G \times w_G) \quad \textit{... Equation 2}$$

Where IA_{AMR} stands for the overall information availability level of absolute maximum ratings

IA_{ROC} stands for the overall information availability level of recommended operating conditions

$IA_{A,\,B\ldots G}$ stands for the information availability level of each constituent (A to G)

7.1.3. Implications of Information Availability Levels

The information availability level is then interpreted for decision-making. The implications of the information availability level are specified in Table 15. The information availability level helps the user assess their confidence in using the available information. These levels serve as guidelines for users to evaluate the information and make process-related decisions.

Table 15: Implications of Information Availability Levels

Information Availability Level	**Implication**
High	We have all the required information.
Moderate-High	The available information has been interpreted to fit the requirements. We can use this information, but the assumptions must be documented. Additional assessments may be required later in the design process.
Moderate-Low	The information is difficult to interpret or does not match the intent of the standard. This information should not be used till the manufacturer confirms it. The part should not be used till the information can be confirmed.
Low	We do not have all the information. This information should not be used till a higher level is achieved. The user should look for other parts.

The information availability level is not a static assignment. These levels can improve as more information is available from the manufacturer. The goal of this methodology is to identify ways of enhancing information availability. It allows the user to identify the gaps in information published in the datasheets by the manufacturers and document them for verification. The process to assess the information availability level and the source of the obtained information is presented in Figure 13.

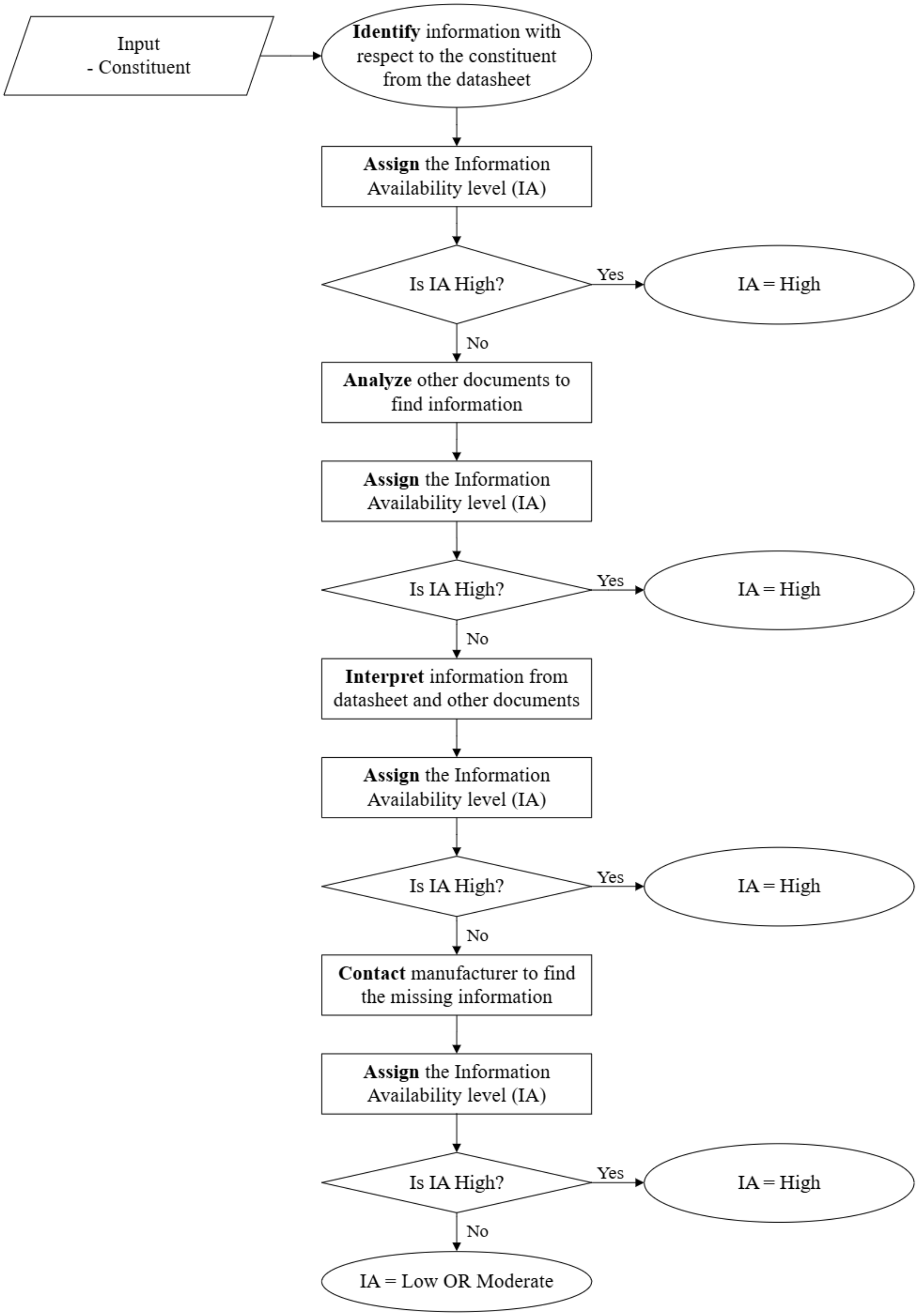

Figure 14: Process to Assess the Information Availability Level for the Constituent Under Consideration

The process is carried out for each constituent. The goal is to achieve a “high” information availability level. The first step is to “identify” the thermal information in the datasheet. All the information is recorded in the thermal ratings document (Appendix A). This step is the initial assessment of the thermal information based on which the information availability level is assigned. If the level achieved is not “high,” we need to move to the next step, that is, “analyze” other documents to find information. In this step, the user should look for information in other parts of the datasheet, thermal documentation, application notes, and qualification reports. The information availability is again assigned to the new information. If the level achieved is not “high,” the information already available to the user is interpreted based on the user’s requirements. An example of this is calculating operating temperature limits using storage temperature, power dissipation, and thermal resistance, which is shown further in Section 7.2.2. If the information availability level is still not “high”, the user can contact the manufacturer to obtain the missing information and to confirm the interpretations. If information is attained through manufacturer communication, the information availability level is reassessed. If the level is still not “high”, this loop ends, and the user should interpret the implication of the information availability level. If at any point during this process, the availability level “high” is achieved, the process ends, and the implication of the information availability level should be interpreted.

7.2. Establishing Absolute Maximum Ratings

AMR represents the temperatures beyond which the component has the possibility of failure. The first step in establishing the absolute maximum ratings is to assign an information availability level, which is presented in Section 6.2.1. The process of assessing the information availability level assists and guides the user in attaining more information through various sources. The goal of this process is to attain more information and increase the information availability level. This process is followed to establish the three key pieces of information for the AMR section to be considered complete: the maximum and minimum values for the operating temperature parameters, the maximum and minimum values for the storage temperature parameters, and the possibility of damage and reliability concerns beyond the AMR. Another method to obtain information related to the temperature values is presented in section 6.2.2.

7.2.1. Information Availability Level

The constituents of information availability and the information scenarios are first documented. Then, each constituent is assigned an information availability level. Some explanations and examples of information availability levels are listed in Table 16.

Table 16: Explanations and Examples of Information Availability Levels for Absolute Maximum Ratings

<table>
<tr><th>Information Availability Level</th><th>Constituent</th><th>Information Available</th></tr>
<tr><td rowspan="4">Level 1: Information is unavailable</td><td>A: Definition of the rating title</td><td>Missing</td></tr>
<tr><td>B: Storage temperature values</td><td>Missing</td></tr>
<tr><td>C: Operating temperature values</td><td>Missing</td></tr>
<tr><td>D: Definition of the temperatures used</td><td>Missing</td></tr>
<tr><td rowspan="3">Level 2: Information is available but inconsistent with industry standards.</td><td>A: Definition of the rating title</td><td>Example: “Protection functions are intended to avoid IC damage in fault conditions and are not intended for continuous operation. Continuous or repetitive operation of protection functions may reduce the IC lifetime [65].”</td></tr>
<tr><td>B: Storage temperature values</td><td>-</td></tr>
<tr><td>C: Operating temperature values</td><td>-</td></tr>
</table>

Information Availability Level	Constituent	Information Available
	D: Definition of the temperatures used	Yes
Level 3: Information is available and matches the intent of the industry standards	A: Definition of the rating title	Example: "Stresses greater than those listed [under Absolute Maximum Ratings] may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at these or any other conditions outside those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may adversely affect reliability [66]."
	B: Storage temperature values	-
	C: Operating temperature values	-
	D: Definition of the temperatures used	-
Level 4: Information is available	A: Definition of the rating title	Ideal definition from the IEC standard: "Absolute maximum ratings are limiting values of operating and environmental conditions applicable to any electronic device of a specified type as defined by its published data, which should not be exceeded under the worst probable conditions [67]."
	B: Storage temperature values	Provided
	C: Operating temperature values	Provided
	D: Definition of the temperatures used	Provided

7.2.2. Using Storage Temperature to Establish Operating Temperature

We have seen that in many cases, the absolute maximum ratings are provided only in terms of storage temperature and not the operational temperature. When operating temperatures are not provided in the absolute maximum ratings, we can utilize the storage temperature values to set the operational temperature limit. In the datasheets, the storage temperature is specified as either of the following: case or junction. Various scenarios for specifying the storage and operating temperatures in the AMR section include:

- Only the storage temperature is specified, but the operational temperature is not specified.
- Both storage temperature and operational temperature are specified and have the same values.
- Both storage temperature and operational temperature are specified and have different values (the operating temperature is lower than the storage temperature).

In many datasheets, the operational junction temperature (T_J) is rated at the same value as the storage junction temperature ($T_{Stg,\ J}$). In storage conditions, the case and junction temperatures are equal. In cases where the storage temperature is provided in terms of case temperature, the case temperature can be assumed to be the maximum junction temperature. Using thermal characteristics, a case temperature (T_C) can be estimated and used as the operational limit. This method is only applicable to the higher temperature limit.

Example: Samsung DRAM – K4A8G165WC [38],

Maximum storage case temperature,

$$T_{Stg,C} = 100℃$$

At storage $T_{Stg,C} = T_{Stg,J}$, therefore, the maximum storage junction temperature,

$$T_{Stg,J} = 100℃$$

Assuming maximum operating junction temperature = maximum storage temperature,

$$T_J = T_{Stg,J}$$

Assuming $\theta_{JC} = 1.7°C/W$, from a similar part from Samsung [68], and $P = 1.5\,W$ from a Micron document [69].

Now, estimate the maximum operating case temperature,

$$T_J = T_C + P \times \theta_{JC}$$

$$100 = T_C + 1.5 \times 1.7$$

$$\boldsymbol{T_C = 97.45\,°C}$$

The operating case temperature can be estimated for various power dissipations based on the application. This method should be applied as a last resort when the user does not have enough information from the manufacturer regarding the operational limits for the device and does not have the time or resources for electrical testing. Using the storage temperature directly to estimate the case temperature assumes that the maximum junction storage temperature is the same in storage and operation. Many failure mechanisms exist in an electronic device at higher operating temperatures, which should be accounted for in the assessment. Values obtained from this method will be Level 2 in the information availability metric.

7.3. Establishing Recommended Operating Conditions

The definition of the recommended operating conditions should specify if the electrical specifications are guaranteed within the temperature range specified by the manufacturer.

7.3.1. Information Availability Level

The information availability is first assigned to assess the quality of the information directly from the datasheet. Explanations and examples of different information availability levels for each constituent for recommended operating conditions are covered in Table 16.

Table 17: Explanations and Examples of Information Availability Levels for Recommended Operating Conditions

Information Availability Level	**Constituent**	**Information Available**
Level 1: Information is unavailable	Availability	*Missing*
	Definition of the rating title	*Missing*
	Temperature range values	Missing. Only AMR provided [46].
Level 2: Information is available but inconsistent with industry standards.	Availability	Example: “Functional Range”
	Definition of the rating title	“Within the functional or operating range, the IC operates as described in the circuit description. The electrical characteristics are specified within the conditions given in the Electrical Characteristics tables [39].”
	Temperature range values	Yes
Level 3: Information is available and matches the intent of the industry standards	Section title	Example: “Component Operating Temperature Range”
	Definition	“Operating Temperature T_{OPER} is the case surface temperature on the center/top side of the DRAM. Some applications require operation of the Extended Temperature Range between 85°C and 95°C case temperature. Full specifications are guaranteed in this range,” but “additional conditions apply [42].”
	Temperature range values	Yes
Level 4:	Section title	“Recommended Operating Conditions.”

Information Availability Level	Constituent	Information Available
Information is available	Definition	"The ratings on the device within which its electrical specifications are guaranteed [70]."
	Temperature range values	Yes

Scenarios like the above are assessed, and the information availability level is assigned.

7.3.2. Confirming Key Points for Recommended Operating Conditions

At the end of this process, the user should be able to satisfy the three conditions for complete recommended operating conditions: whether the manufacturer guarantees electrical specifications, whether the minimum and maximum values for each temperature range are provided, and whether the operational restrictions, if any exist, are specified. If these conditions are not met, the user does not have complete information on recommended operating conditions.

8. Uprateability Assessment Process

Uprateability assessment is the process through which a part is identified as a candidate for uprating for an application through the analysis and interpretation of technical literature from the manufacturer and other sources. This initial assessment of parts determines if they should be considered for further uprating assessment. The focus of this study is "thermal uprateability assessment", which assesses if a part can be considered a candidate for uprating beyond the manufacturer's "temperature" limits. This process is based on thermal information available from the manufacturers and other technical literature on absolute maximum ratings, recommended operating conditions, and the variation in electrical characteristics of the part with temperature. Therefore, this information should be obtained before a decision can be made regarding the uprateability of the part.

In this section, the process of uprateability assessment is described. The process starts with collecting the user's requirements, assessing the thermal information (establishing it if required), assessing the need for uprateability, and finally assessing if the part is uprateable. This is a multi-step process, and some parts of this process can be used regardless of the uprateability assessment.

8.1. Application Background and Part Requirements

The first step is to identify the application in which the component is to be used. The user defines the application, the function of the component in the application, and the specification requirements of the component based on the function. This information is collected in the "Uprateability Assessment Data Collection" document shown in Appendix B. The application background provides insight into the usage conditions, mounting location, and hours of operation. The parts are selected based on the user's requirements:

- Ambient temperature around the mounting location in the vehicle
- Maximum power dissipation for the application
- Electrical specifications of the part for the application (resistance, frequency, memory, or supply voltage)
- Part packaging and footprint limitations
- Physical parameters like weight and size of the component.

More specifications can be required based on the part type. A pool of candidate parts is identified based on the initial required specifications. At this stage, the part has not been assessed for uprateability.

8.2. Part Thermal Ratings Assessment

Once a pool of candidate parts is identified, the thermal ratings of the parts must be determined. This includes absolute maximum ratings and recommended operating conditions. This step is necessary to assess the need for uprateability further. The process for part thermal ratings assessment is shown in Figure 15.

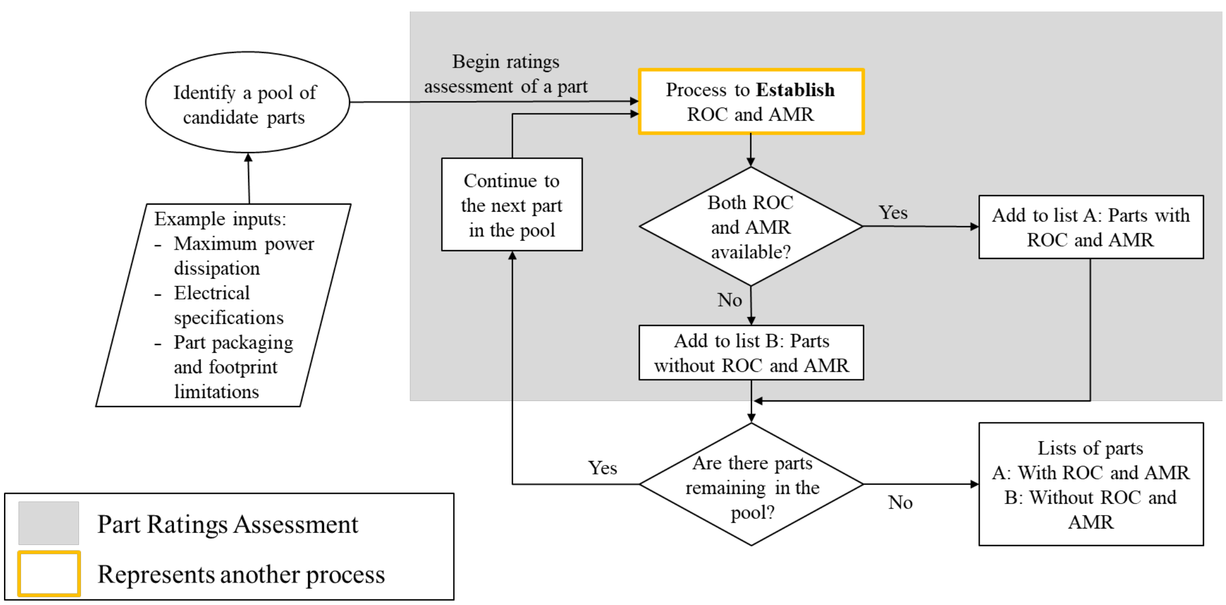

Figure 15: Part Thermal Ratings Assessment Process

This process accepts the part requirements as inputs and starts with an initial pool of candidate parts that have been identified based on these requirements. One part is selected at a time from the pool and goes through this assessment process. The first step is to establish recommended operating conditions and absolute maximum ratings. This follows the process developed in section 5. The thermal information for each part must be assessed, and an information availability level assigned. The three key parameters for recommended operating conditions and absolute maximum ratings must be satisfied. If they are satisfied for both AMR and ROC, the part is added to “list A (Parts with ROC and AMR)”. Otherwise, the part is added to “list B (Parts without ROC and AMR)”. For any part, it is recommended to achieve an information availability level of at least ‘moderate-high’ before moving to the next step of uprateability assessment. This process is continued till all the parts are exhausted from the pool, and the user obtains two lists of parts (A and B).

8.3. Determine the Need for Uprateability Assessment

In this step, we analyze if the target temperature of the application falls within the established recommended operating conditions. This process requires three inputs: target temperature range, recommended operating conditions, and the absolute maximum ratings. The list of parts considered for this process is the “list A” identified in the part rating assessment (section 8.2). Target temperature range is the temperature range within which the component is intended to be operated in a product, which should be defined consistently as ambient, case, or junction temperature. For this study, the target temperature range limits are denoted as $T_{Target, min}$ to $T_{Target, max}$.

A part is selected from the list, and its temperature limits in the absolute maximum ratings are compared with the target temperature range. If the target temperature range is outside the absolute maximum ratings, the part cannot be uprated. A part should not be used outside the AMR. However, if the target temperature range is within the AMR, the next condition is checked. The next test condition is to check whether the target temperature range is within the recommended operating conditions. If the target temperature range is within the temperature range in recommended operating conditions, uprating is not required for the part in consideration and is added to “Pool C (Uprating not required)”. If the target temperature range is outside the recommended operating conditions, the part is added to pool D (Needs to be assessed for uprateability).

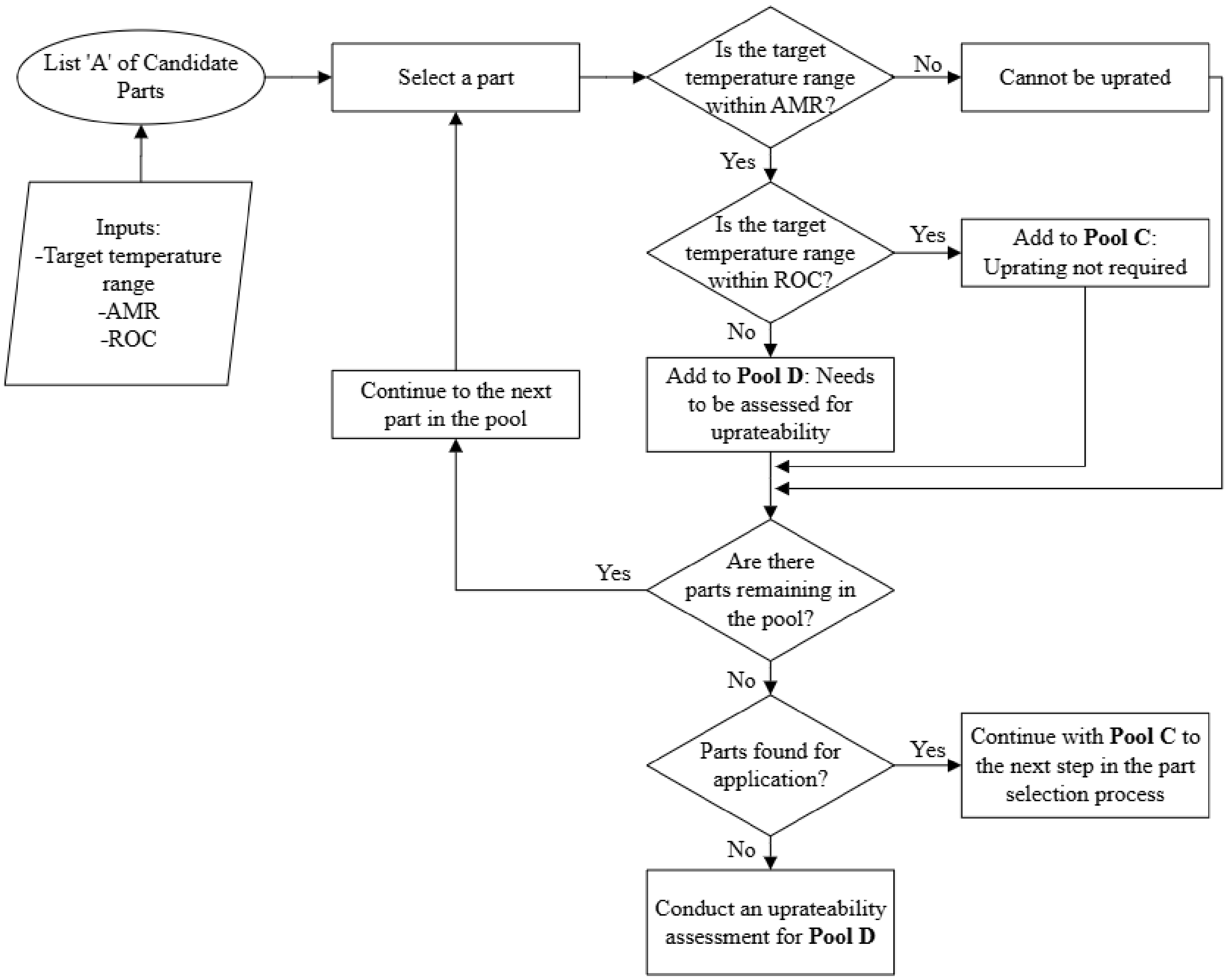

Figure 16: Determining the Need for Uprateability Assessment

Once all the parts are exhausted from the initial pool, the two resulting pools are analyzed. For Pool C, the user can stop the assessment process and decide to use the part since they do not need to be uprated. For Pool D, however, the process continues to the next step, where the uprateability assessment begins.

8.4. Uprateability Assessment

The parts identified as 'Pool D' from the previous process (section 8.3) need to be assessed for uprateability. In this process, it is determined if a part has the potential to be uprated for the target temperature range. The inputs to this process are the target temperature range and the operational requirements. The operational requirements represent the electrical parameters that are critical to the application and their expected values. This information is also collected from the user in the uprateability assessment data collection document in Appendix B. The uprateability assessment process is shown in Figure 17.

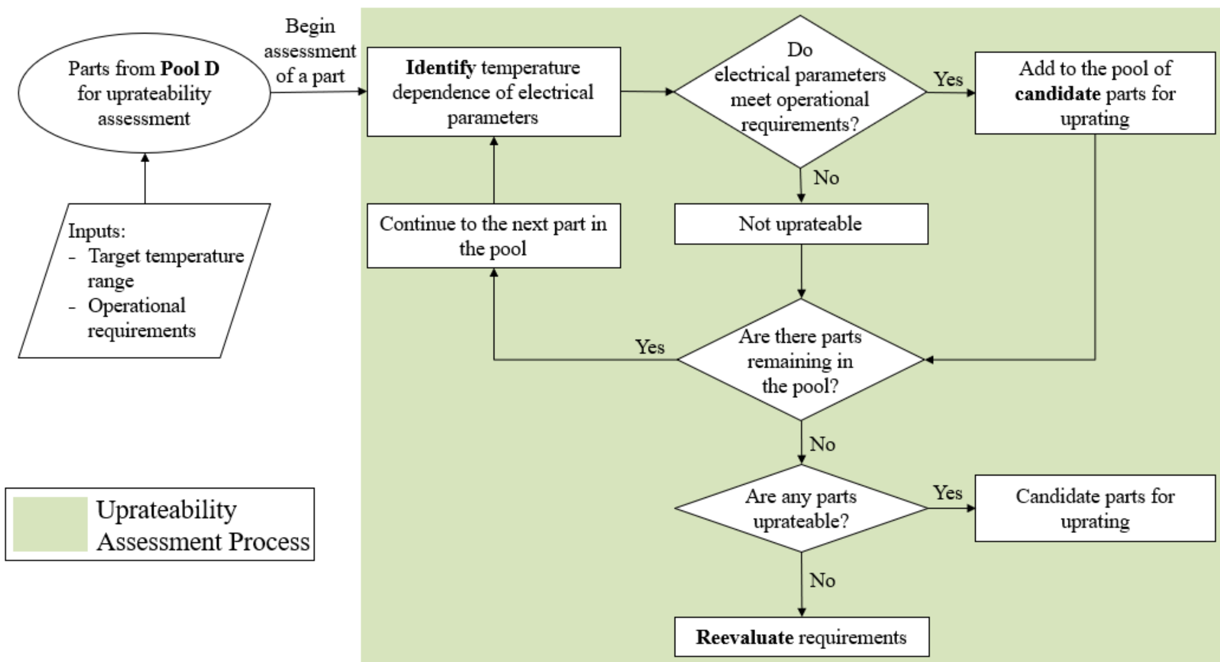

Figure 17: Uprateability Assessment Process

The process begins by selecting one of the parts from Pool D. For this part, the temperature dependence of critical electrical parameters is identified. This can be available in the datasheets as discrete data points that provide the value of the parameter at certain temperatures, or a graphical representation of electrical parameters with respect to temperature as characteristic curves. An example of discrete data points in datasheets is shown in Figure 18. This graph is created from the refresh rates provided in the datasheets at different temperatures.

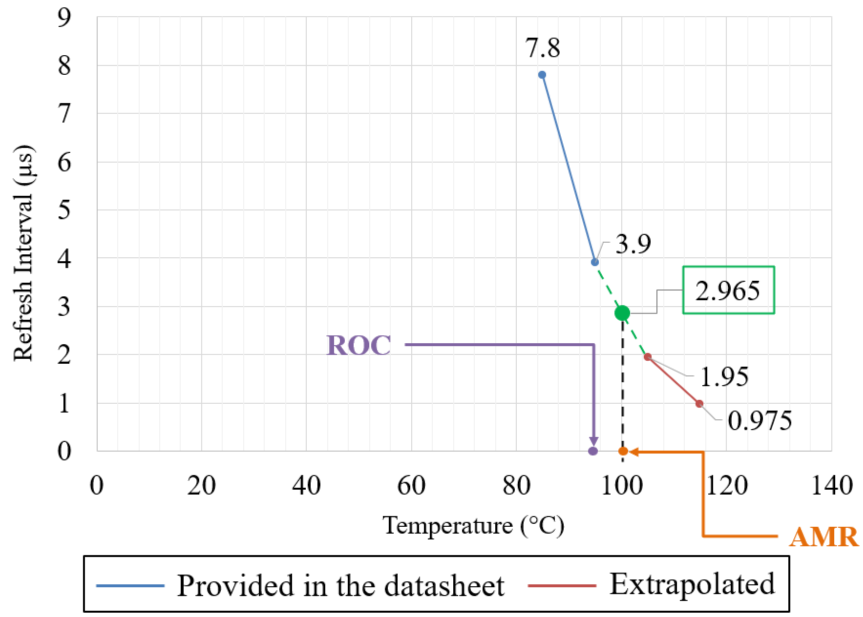

Figure 18: Refresh Rate Values at 85, 95, 105, and 115 °C for a Samsung DRAM [42]

Another example of temperature dependence of electrical parameters is the form of characteristic curves, as shown in *Figure 18*.

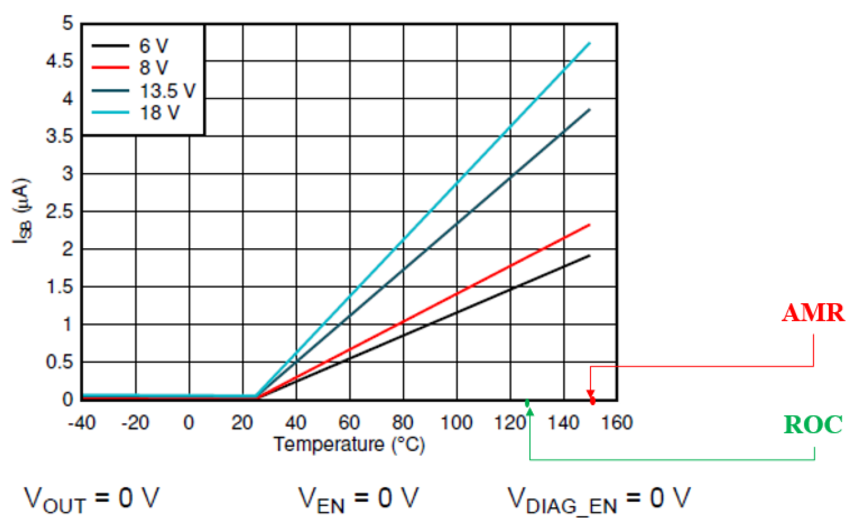

Figure 19: Characteristic Curve for Standby Current (ISB) vs Temperature for Texas Instruments Power Switch [71]

Information on the temperature dependence of electrical parameters can also be found in the literature. Figure 19 shows an experimental evaluation of DRAMs that measures the errors in the DRAM with increasing temperature and at different refresh rates. Such information can be used to perform parameter recharacterization, where "part functionality is assessed and the electrical parameters are characterized over the target temperature range, leading to a possible respecification of the manufacturer-specified parameter limits [3]."

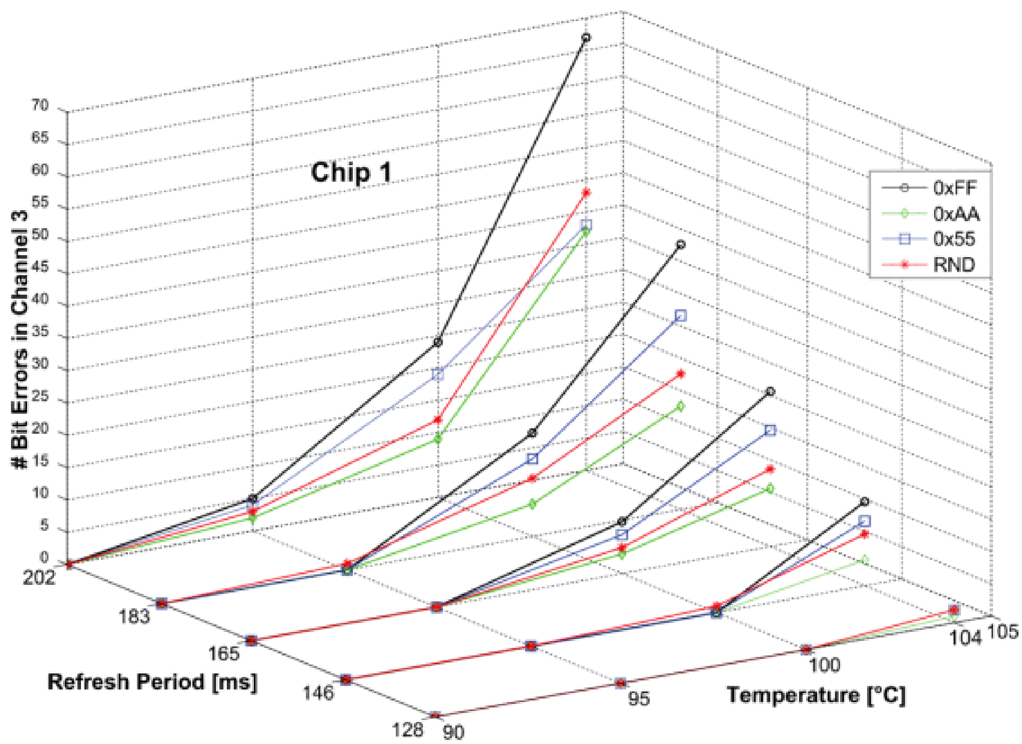

Figure 20: Experimental Results for Retention Time Measurements and Modeling of Bit Error Rates of WIDE I/O DRAM [72]

If the temperature dependence of electrical parameters is not provided in the datasheet, the user should look for this information in other documents, like the thermal information document, application notes, and qualification reports. The user can also look for this information in the published literature. However, it is difficult to obtain such information for a particular part number.

Once the temperature dependence of electrical parameters is identified, the values are checked against the user's operational requirements. The data published by the manufacturer regarding the variation in electrical parameters with respect to temperature is compared to the user's operational requirements. By setting one of the input parameters below the acceptable limit, if the characteristic trends appear to be consistent and if they continue (are monotonic) within the target temperature range, the component can meet the user's requirements. If the part meets the operational requirements, it is considered a candidate part for uprating. This process is repeated till all the parts from the pool are exhausted.

Once the pool of candidate parts is exhausted, the user must check if any parts are found to be uprateable. If a group of parts is identified by the end of the uprateability process, they will be validated through testing. The candidate parts for uprating will be ranked based on the level of uprateability. This ranking is based on which part is most desirable based on the potential to be uprated. This ranking does not consider the cost of the part, authorized distributors, availability, and obsolescence. The business decision regarding the supply chain will be made as a separate step after the uprateability is assessed.

If no parts are found to be uprateable after all the candidate parts are exhausted from the pool, the user must reevaluate the requirements. The requirements can be re-evaluated by:

- Reducing the required target temperature range or reducing the performance requirement,
- Introducing redundancy in the product to distribute the load on the components, or

- Redesigning the thermal management system to ensure better heat dissipation.

Using the uprateability assessment process, the user can identify parts that have the potential to be uprated. The uprateability assessment is an initial assessment of the parts considered for use beyond the manufacturer's temperature specifications. At the end of this process, the part is not guaranteed to be uprateable and should not be used prior to electrical testing. The next section presents three case studies to validate the developed process.

9. Case study

This section presents two case studies for the uprateability assessment process developed in Section 8. In the study, we identify the component type, the application for which the part is to be used, and the required specifications of the part. The inputs for the uprateability assessment process are collected using the data collection document. Based on the required specifications, a pool of candidate parts is identified, and one part from the pool is run through the uprateability assessment process as an example.

9.1. DRAMs

The first case study presented was one of DRAMs. The application and operational requirements are collected, and candidate parts are selected for the application.

9.1.1. Application Background and Operational Requirements

The application background is obtained from the user in the data collection document. In this case study, a DRAM is being assessed for a navigation console. This information is entered into the uprateability assessment data collection document, as shown in Figure 21.

Component and its application:	
Component type	DRAM
Specification	DDR4 4GB
Application	Navigation console
Function in the application	Data storage, temporary storage and buffering
Mounting location	Center of the dashboard

Figure 21: Application and Operational Requirements for a DRAM in Centralized Control Module

The requirements to identify the initial pool of components are provided in Table 18.

Table 18: Requirements to Identify Initial Candidate Parts

Parameter	**Requirement**
Ambient temperature around the mounting location in the vehicle	-40 to 95°C
Memory capacity	4GB
Maximum power dissipation	1.5 W
Electrical specifications	Supply voltage = 1.2V
Part packaging	Area array package
Footprint limitation	6.5 x 12 mm
Dimensions of the component	Maximum dimensions: 7.5 x 13.5 mm

An initial pool of candidate parts is selected based on the user's requirements. In this case study, three such parts are identified:

- Samsung 4GB DRAM: K4A4G165WE
- Micron 4GB DRAM: MT40A512M8
- Samsung 4GB DRAM: K4A4G085WE

These parts meet the user's initial criteria and hence are chosen for the uprateability assessment process.

9.1.2. Part Thermal Ratings Assessment

The first step is to establish the thermal ratings for each part. The absolute maximum ratings section from the datasheet for Samsung 4GB DRAM K4A4G165WE is shown in Figure 22.

Symbol	Parameter	Rating	Units	NOTE
VDD	Voltage on VDD pin relative to Vss	-0.3 ~ 1.5	V	1,3
VDDQ	Voltage on VDDQ pin relative to Vss	-0.3 ~ 1.5	V	1,3
VPP	Voltage on VPP pin relative to Vss	-0.3 ~ 3.0	V	4
V_{IN}, V_{OUT}	Voltage on any pin except VREFCA relative to Vss	-0.3 ~ 1.5	V	1,3,5
T_{STG}	Storage Temperature	-55 to +100	°C	1,2

NOTE :
1. Stresses greater than those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability
2. Storage Temperature is the case surface temperature on the center/top side of the DRAM. For the measurement conditions, please refer to JESD51-2 standard.
3. VDD and VDDQ must be within 300 mV of each other at all times;and VREFCA must be not greater than 0.6 x VDDQ, When VDD and VDDQ are less than 500 mV; VREFCA may be equal to or less than 300 mV
4. VPP must be equal or greater than VDD/VDDQ at all times.
5. Overshoot area above 1.5 V is specified in section 8.3.4, 8.3.5 and section 8.3.6..

Figure 22: Absolute Maximum Ratings Section from the Datasheet for Samsung DRAM – K4A4G165WE [42]

The information available with respect to each constituent is tabulated, and the information availability level is assessed. The information availability level assessment is shown in Table 18.

Table 19: Information Availability Assessment for Absolute Maximum Ratings for Samsung DRAM – K4A4G165WE

Constituent	Description	Information Available	Information Availability Number	Information Availability Level
A	Definition of the rating title	Stresses greater than those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at these or any other conditions above those indicated in the operational	3	Moderate High

Constituent	Description	Information Available	Information Availability Number	Information Availability Level
		sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.		
B	Storage temperature values	-55 to +100 °C	4	High
C	Operating temperature values	Missing	1	Low
D	Definition of the temperatures used	Storage Temperature is the case surface temperature on the center/top side of the DRAM	4	High

The overall information availability level of the absolute maximum ratings section can be calculated by using equation (1) and weights from Table 14.

$$IA_{AMR} = (IA_A \times w_A) + (IA_B \times w_B) + (IA_C \times w_C) + (IA_D \times w_D)$$

$$IA_{AMR} = (\mathbf{3} \times 0.3) + (4 \times 0.1) + (1 \times 0.3) + (4 \times 0.3)$$

$$IA_{AMR} = 2.8 \sim \mathbf{3}$$

Therefore, the overall information availability level of the absolute maximum ratings section is "**Moderate**". The moderate level indicates that the available information has been interpreted to meet the requirements. We can use this information, but the assumptions must be documented. To increase the overall information availability level, the level for constituent C must be increased. This can be achieved by using the method provided in Section 6.2.2, increasing the information availability level for constituent C to 2. The user must note that these values are obtained by making many assumptions and, therefore, must be confirmed before usage by the manufacturer or via testing. However, by using these methods, the overall information availability level can be increased to **3.1**. To achieve a higher information availability level, the user must contact the manufacturer.

The recommended operating conditions section from the datasheet is shown in Figure 23. This information will be used to assess the information availability level.

Symbol	Parameter		rating	Unit	NOTE
T_{OPER}	Operating Temperature Range	Normal	0 to 95	°C	1, 2, 4
		Industrial	-40 to 95	°C	1, 3, 4

NOTE :
1. Operating Temperature T_{OPER} is the case surface temperature on the center/top side of the DRAM.
2. The Normal Temperature Range specifies the temperatures where all DRAM specifications will be supported. During operation, the DRAM case temperature must be maintained between 0-85°C under all operating conditions
3. The Industrial Temperature Range specifies the temperatures where all DRAM specifications will be supported. During operation, the DRAM case temperature must be maintained between -40-95°C under all operating conditions
4. Some applications require operation of the Extended Temperature Range between 85°C and 95°C case temperature. Full specifications are guaranteed in this range, but the following additional conditions apply:
   a) Refresh commands must be doubled in frequency, therefore reducing the refresh interval tREFI to 3.9us.
   b) If Self-Refresh operation is required in the Extended Temperature Range, then it is mandatory to use the Manual Self-Refresh mode with Extended Temperature Range capability (MR2 A6 = 0_b and MR2 A7 = 1_b).

Figure 23: Recommended Operating Conditions Section for Samsung DRAM – K4A4G165WE [42]

The information available for each constituent is tabulated, and the information availability level is assessed. The information availability level assessment is shown in Table 20.

Table 20: Information Availability Assessment for Recommended Operating Conditions for Samsung DRAM – K4A4G165WE [44]

Constituent	**Description**	**Information Available**	**Information Availability Number**	**Information Availability Level**
E	Availability	Titled: "DRAM Component Operating Temperature Range"	3	Moderate High
F	Definition of the rating title	"Full specifications are guaranteed in this range, but the following additional conditions apply…"	3	Moderate High
G	Temperature range values	-40 to +95 °C	4	High

The overall information availability level of the recommended operating conditions can be calculated by using equation (2) and weights from Table 14.

$$IA_{ROC} = (IA_E \times w_E) + (IA_F \times w_F) + (IA_G \times w_G)$$

$$IA_{ROC} = (3 \times 0.25) + (3 \times 0.25) + (4 \times 0.5)$$

$$IA_{ROC} = 3.5 \sim \mathbf{4}$$

Therefore, the overall information availability level of the recommended operating conditions section is "High". The high level indicates that all the required information is available. The user can confidently use this information.

9.1.3. Need for Uprateability Assessment

The target temperature for the application is also defined in the data collection document, as shown in Figure 24.

Target temperature			
Temperature (°C)	Ambient	Junction	Case
Minimum			-40
Maximum			100

Figure 24: Target Temperature Range for the DRAM in a Centralized Control Module

The target temperature range is **within the absolute maximum ratings** and **outside the recommended operating conditions**. Therefore, the part needs to be uprated and should be added to Pool D.

9.1.4. Uprateability Assessment Process

The inputs to the uprateability assessment process are the target temperature range and operational requirements. The operational requirements are entered into the uprateability assessment data collection document as shown in Figure 25.

Critical parameters	Units	Allowable values	
		Min	Max
Refresh time	µs	0.9	64
Cycle time	ns	18	22
Data transfer rate	Mega Transfers/s	2666	3200
Bandwidth	GB/s	10	-
Operating frequency	MHz	4500	-

Figure 25: Critical Electrical Parameters for a DRAM in Centralized Control Module

For the DRAM, the most critical electrical parameter is refresh rate, which is extracted from the datasheet and plotted in a graphical representation in Figure 26. In this image, the blue data points represent the refresh rate provided by the manufacturer at 85°C and 95°C, and the red data points represent the refresh rates extrapolated by reducing the refresh time by half for every 10°C rise in temperature.

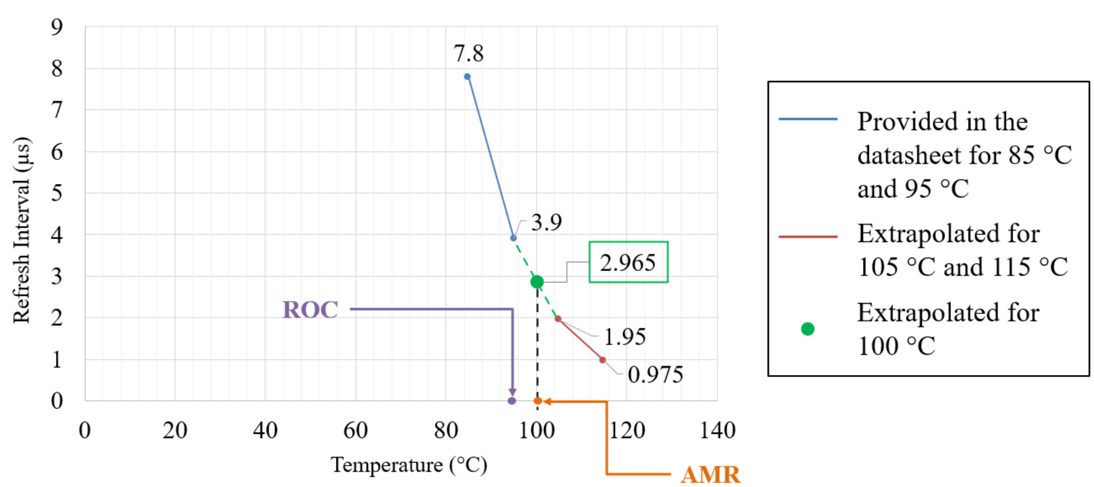

Figure 26: Graphical Representation of Refresh Rates for Samsung DRAM – K4A4G165WE [42]

The datasheet provides the refresh interval up to 95 °C. It also instructs that the refresh interval should be reduced by half with every 10 °C increase in temperature. Based on this information, the refresh interval values were extrapolated for 105°C and 115°C. And then for 100°C. If the characteristic trends appear to be consistent within the target temperature range, the component can meet the user's requirements. The refresh rate at 115°C is within the operational requirements defined in Figure 25. Hence, this part can be considered for uprating.

9.2. Power Switches

The second case study is for a power switch. The application is determined, operational requirements are collected, and candidate parts are selected for the application.

9.2.1. Application Background and Operational Requirements

The application background is obtained from the user in the data collection document. In this case study, a power switch is being assessed for a zone electronic control unit (ECU). This information is entered into the uprateability assessment data collection document, as shown in Figure 27.

Component and its application:

Component type	Power Switch
Specification	12V (Minimum)
Application	Zone Electronic Control Unit (ECU)
Function in the application	On-off function
Mounting location	Engine Compartment

Figure 27: Application and Operational Requirements for a Power Switch in Zone ECU

The user's requirements to identify the initial pool of components are provided in Table 21. These requirements consist of form, fit, and function of the component.

Table 21: Requirements to Identify Initial Candidate Parts for Zone ECU

Parameter	**Requirement**
The ambient temperature around the mounting location in the vehicle	-40 to 150 °C
Electrical specifications	Minimum supply voltage = 12V
Part packaging	Thin Shrink Small Outline Package (TSSOP)
Dimensions of the component	Maximum dimensions: 5.5 x 5.5 mm

An initial pool of candidate parts is selected based on the user's requirements. In this case study, three such parts are identified:

- Infineon – BTS70402EPA
- Texas Instruments – TPS2HB50-Q1
- NXP Semiconductors – MC12XS6D4

These parts meet the user's initial criteria and hence are chosen for the uprateability assessment process.

9.2.2. Part Thermal Ratings Assessment

The first step is to establish the thermal ratings for each part. The absolute maximum ratings section from the datasheet for Texas Instruments TPS2HB50-Q1 is shown in Figure 28.

		MIN	MAX	UNIT
Maximum continuous supply voltage, V_{BB}			36	V
Load dump voltage, V_{LD}	ISO16750-2:2010(E)		40	V
Reverse battery voltage, V_{Rev}, $t \leq 3$ minutes		–18		V
Enable pin voltage, V_{EN}		–1	7	V
LATCH pin voltage, V_{LATCH}		–1	7	V
Diagnostic Enable pin voltage, V_{DIA_EN}		–1	7	V
Sense pin voltage, V_{SNS}		–1	18	V
Select pin voltage, V_{SEL1}		–1	7	V
Reverse ground current, I_{GND}	$V_{BB} < 0$ V		–50	mA
Energy dissipation during turnoff, E_{TOFF}	Single pulse, L_{OUT} = 5 mH, $T_{J,start}$ = 125°C		17(2)	mJ
Energy dissipation during turnoff, E_{TOFF}	Repetitive pulse, L_{OUT} = 5 mH, $T_{J,start}$ = 125°C		7(2)	mJ
Maximum junction temperature, T_J			150	°C
Storage temperature, T_{stg}		–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute maximum rated conditions for extended periods may affect device reliability.

(2) For further details, see the section regarding switch-off of an inductive load.

Figure 28: Absolute Maximum Ratings Section for Texas Instruments Power Switch – TPS2HB50-Q1 [73]

The information available with respect to each constituent is tabulated, and the information availability level is assessed. The information availability level assessment is shown in Table 22.

Table 22: Information Availability Assessment for Absolute Maximum Ratings for Texas Instruments Power Switch – TPS2HB50-Q1

Constituent	**Description**	**Information Available**	**Information Availability Number**	**Information Availability Level**
A	Definition of the rating title	Stresses greater than those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions	3	Moderate High

Constituent	Description	Information Available	Information Availability Number	Information Availability Level
		for extended periods may affect reliability.		
B	Storage temperature values	-55 to +100 °C	4	High
C	Operating temperature values	T_J = 150 °C	4	High
D	Definition of the temperatures used	Storage Temperature is the case surface temperature on the center/top side of the DRAM	1	Low

The overall information availability level of the absolute maximum ratings section can be calculated by using equation (1) and weights from Table 14.

$$IA_{AMR} = (IA_A \times w_A) + (IA_B \times w_B) + (IA_C \times w_C) + (IA_D \times w_D)$$

$$IA_{AMR} = (\mathbf{3} \times 0.3) + (4 \times 0.1) + (4 \times 0.3) + (1 \times 0.3)$$

$$IA_{AMR} = 2.8 \sim \mathbf{3}$$

Therefore, the overall information availability level of the absolute maximum ratings section is "**Moderate**". The moderate level indicates that the available information has been interpreted to meet the requirements. We can use this information, but the assumptions must be documented.

The recommended operating conditions section from the datasheet is shown in . This information will be used to assess the information availability level.

		MIN	MAX	UNIT
V_{BB}	Nominal supply voltage (1)	6	18	V
V_{BB}	Extended lower supply voltage	3	6	V
V_{BB}	Extended higher supply voltage(2)	18	28	V
V_{EN}	Enable voltage	–1	5.5	V
V_{LATCH}	LATCH voltage	–1	5.5	V
V_{DIA_EN}	Diagnostic Enable voltage	–1	5.5	V
V_{SEL1}	Select voltage	–1	5.5	V
V_{SNS}	Sense voltage	–1	7	V
T_A	Operating free-air temperature	–40	125	°C

(1) All operating voltage conditions are measured with respect to device GND.
(2) Device parameters still valid, short circuit protection valid to value specificed by V_{SC} parameter.

Figure 29: Recommended Operating Conditions Section for Texas Instruments Power Switch – TPS2HB50-Q1 [73]

The information available for each constituent is tabulated, and the information availability level is assessed. The information availability level assessment is shown in Table 23.

Table 23: Information Availability Assessment for Recommended Operating Conditions for Texas Instruments Power Switch – TPS2HB50-Q1 [73]

Constituent	**Description**	**Information Available**	**Information Availability Number**	**Information Availability Level**
E	Availability	Titled: "Recommended Operating Conditions"	4	High
F	Definition of the rating title	"Device parameters still valid…"	3	Moderate High
G	Temperature range values	-40 to +125 °C	4	High

The overall information availability level of the recommended operating conditions can be calculated by using equation (2) and weights from Table 14.

$$IA_{ROC} = (IA_E \times w_E) + (IA_F \times w_F) + (IA_G \times w_G)$$

$$IA_{ROC} = (4 \times 0.25) + (3 \times 0.25) + (4 \times 0.5)$$

$$IA_{ROC} = 3.75 \sim \mathbf{4}$$

Therefore, the overall information availability level of the recommended operating conditions section is “High”. The high level indicates that all the required information is available. The user can confidently use this information.

9.2.3. Need for Uprateability Assessment

The target temperature for the application is also defined in the data collection document, as shown in Figure 30.

Target temperature			
Temperature (°C)	Ambient	Junction	Case
Minimum			-40
Maximum			160

Figure 30: Target Temperature Range for the Power Switch in a Zone ECU

The target temperature range is within the absolute maximum ratings and outside the recommended operating conditions. Therefore, the part needs to be uprated and should be added to Pool D.

9.2.4. Uprateability Assessment

The inputs to the uprateability assessment process are the target temperature range and operational requirements. The operational requirements are entered into the uprateability assessment data collection document. The electrical parameters critical to the application are the quiescent current and the supply voltage as shown in Figure 31.

Critical parameters	Units	Allowable values	
		Min	Max
Supply Voltage	V	12	-
Quiescent Current	mA	3	-

Figure 31: Critical Electrical Parameters for a Power Switch in a Zone ECU

The temperature dependence of quiescent current is identified from the datasheet as shown in Figure 31. The figure shows the absolute maximum ratings and recommended operating conditions as defined in the datasheets and the rated maximum and minimum values of quiescent current. Using the characteristics curves we extrapolate the value of quiescent current at 160 °C.

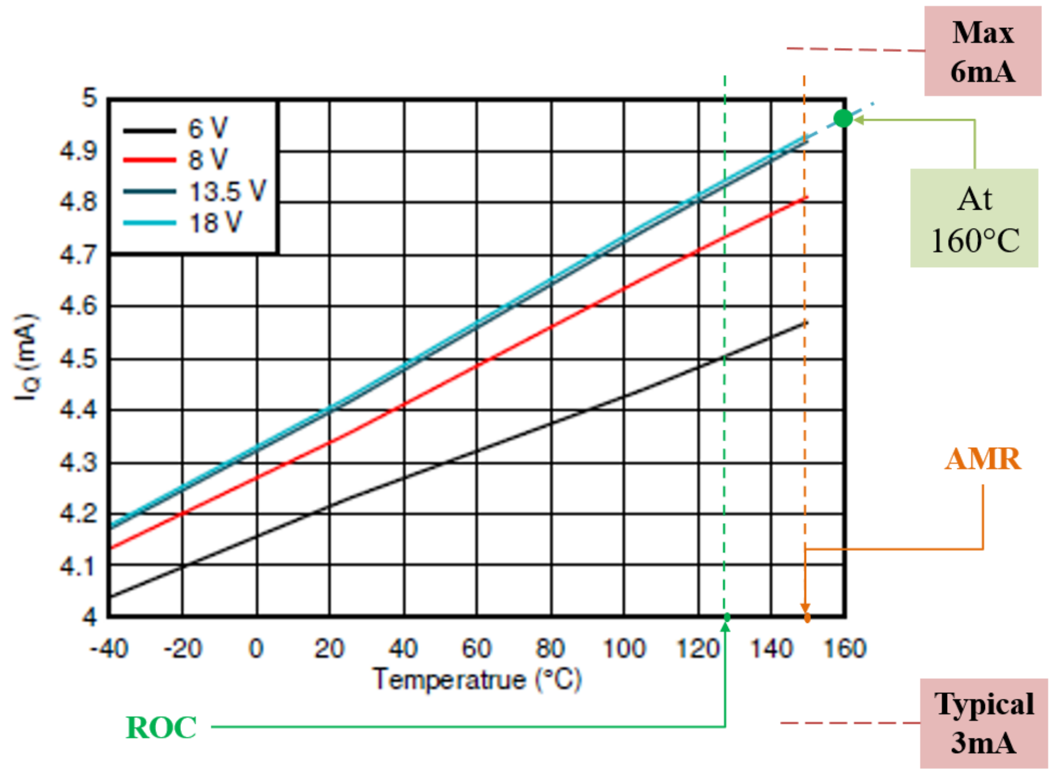

Figure 32: The Temperature Dependence of Quiescent Current for TPS2HB50-Q1 [73]

If the characteristic trends appear to be consistent within the target temperature range, the component can meet the user's requirements. In this case the quiescent current value at 160 °C meets the user's requirements as well as the manufacturer's ratings. Therefore, this part can be considered for uprating.

10. Conclusions, Contributions, and Future Work

This thesis makes significant contributions to the field of part selection and management by making the users aware of the thermal information required for different processes involved in the performance assessment of the parts and how to obtain information when unavailable.

The first contribution lies in the quantitative analysis of the part datasheets across three component classes. The methodologies for part selection and management, derating, uprating, and thermal management rely on the information from the part datasheets. This analysis reveals a concerning trend: all the datasheets analyzed were missing at least one piece of thermal information. There are also inconsistencies in the information provided by manufacturers, which pose challenges in the part selection and management process. Industry standards can assist manufacturers in determining the necessary information to provide in the datasheets. However, the current standards do not contain guidelines for providing all the information necessary for the user. Hence, this thesis includes the list of information required by the users and the guidelines that should be included in the standards. Users often compare the values from different datasheets without completely understanding the implications of the values. Users may not always recognize that the information available to them might be incomplete, and they could benefit more from having access to complete thermal information. This paper increases awareness among users about assessing the completeness of thermal information in the datasheets and how complete information can benefit them in part selection and management. It recognizes the gaps in the information provided by the manufacturers and encourages them to obtain the missing information. This will enhance the quality of the user's part database and aid in more accurate decision-making.

The second contribution lies in establishing part thermal ratings when missing or incomplete in a datasheet. This thesis provides a method to assign an information availability level to absolute maximum ratings and recommended operating conditions that can assist the user in understanding the quality of information available. This level signifies the trust of the user in the information provided and whether it is appropriate for the part to be used in an application. The information availability levels have different implications that guide the user regarding the use of the part in an application. Since the process of assigning availability levels is iterative, the user can strive for a higher level of information availability. This iterative process also assists the user in identifying different sources of obtaining the missing information. This document outlines the essential points needed for absolute maximum ratings and suggested operating conditions, offering guidance to users on the comprehensiveness of these ratings.

The third contribution is the uprateability assessment process. The process of uprating includes testing of parts, which can be expensive and time-consuming. The uprateability assessment process eliminates the parts that do not have the potential to be uprated. This thesis explores the information provided in the datasheets and other associated documents to evaluate whether the parts can be considered for uprating. Through this process, the non-promising parts are eliminated from the initially identified pool of parts, thus reducing the number of parts that require further uprating assessment. Once the parts are identified through uprateability assessment, the parts can further be eliminated based on reliability concerns, difficulties during the assembly, and obsolescence. This will address the parts that cannot be used in an application, even after being identified by the uprateability assessment.

The uprateability assessment process developed in this thesis is dependent on the critical electrical parameters. These parameters are critical to the application and have an acceptable range defined by the user. Therefore, these parameters can be included in the choice of electrical test parameters to test for uprating. The parts deemed uprateable from the uprateability assessment process still need to undergo an uprating assessment before use. The uprateability assessment does not guarantee reliability when a part is uprated. Even if a component is deemed uprateable, other factors such as reliability, obsolescence, and ease of assembly may disqualify it from further consideration. Therefore, it is beneficial to conduct a preliminary evaluation of these aspects—reliability, assembly, and obsolescence—before entering the uprating process. Since this work is based on process development for part selection, future researchers may consider performing a survey of component engineers to validate various assumptions and decisions.

The uprateability assessment process applies to part operation beyond rating, to both higher and lower temperature ranges. While the examples shown in this thesis are for the higher temperature limit, that does not preclude the use of the process at lower temperatures. The process can be applied to the lower temperature limits as well. The user needs to gather information regarding the temperature dependence of electrical parameters in the lower temperature range, either using graphical representations or discrete datapoints for change in electrical parameters with temperature, to assess whether the part is uprateable. When the part identified to be uprateable in the lower temperature range goes through additional assessment, the reliability assessment process may be different since the failure mechanisms operating at that temperature range may be different.

The initial work in uprating does not provide a pre-selection process. This thesis adds a preselection process to the uprating process that reduces the number of parts that need to go through the uprating assessment. The value of this work is not limited only to finding parts that may be uprateable, but also to eliminating parts that will not meet the performance requirements.

Each analysis step in the part selection and management process, including reliability assessment, obsolescence assessment, assembly assessment, and manufacturer assessment, incurs its own cost. Consequently, the down-selection process using this methodology holds significant value. Through the operability assessment process, we eliminate the non-viable parts from consideration. This down-selection process is beneficial because it reduces the need to perform those assessments on parts that are not suitable.

Appendix A: Thermal Ratings Document

The purpose of this document is to facilitate communication between the component user and the manufacturer to establish an agreement regarding the temperature ratings of the component. The user provides the data from the component's datasheet as they understand it. The component manufacturer then validates these interpretations and has the freedom to enter any missing information or make any necessary corrections. This process ensures that both parties have a clear understanding of the temperature ratings and specifications for the component, and any discrepancies can be addressed and corrected. Some relevant definitions:

User: The entity that intends to use the component in an application.

As interpreted by the user: The information documented as interpreted by the user after analyzing the datasheet.

As intended by the component manufacturer: The information to be entered by the manufacturer as defined by them internally.

Temperature Notation Used: The temperature estimation location is indicated in the rating, i.e., case temperature, ambient temperature, and junction temperature.

The first part of the thermal ratings document is used to document the interpretations of the component user and indicate the unavailability of the information in the datasheet (Figure 33).

Temperature Rating Title: The section in the datasheet that provides operating temperature ratings, e.g., Functional Range and operating temperatures.

Temperature location: The temperature estimation location as indicated in the datasheet, e.g., case, junction, ambient.

Specific information on the temperature location: Enter more detailed information on the location of temperature estimation, e.g., for the case temperature at the top/center of the package.

Recommended Operating Conditions

Part Information

Part Number	
Part Manufacturer	
Part Information	
Datasheet Version	
Datasheet Release Date	

To be updated by the component user as interpreted from the datasheet

Operating Conditions title used		
Definition of the title as interpreted by the user		
Operating temperature range available?		
Temperature location		
Any other temperature used		
Specific information on the temperature location		
	Min (°C)	Max (°C)
Temperature range values		

Figure 33: Thermal Rating Document – User Interpretations of the ROC

The second part of the thermal ratings document is used to document the implications of the manufacturer of the information in the datasheet (Figure 34). This part of the document is filled in by the manufacturer if the user requests clarification.

Definition of the title as intended by the manufacturer: Enter the description of the above title as intended.

Are electrical specifications guaranteed: The manufacturer should confirm if full electrical specifications are guaranteed within the temperature range indicated in this section.

To be filled by the component manufacturer as intended when requested by the User

Temperature rating title used		
Definition of the title as intended by the manufacturer		
Temperature location		
Specific information on the temperature location		
	Min	Max
Temperature range values		
Are full electrical specifications guranteed?		

Figure 34: Thermal Rating Document – Manufacturer's Implication for ROC

The thermal rating document documents the user's interpretation of the absolute maximum ratings and confirms with the manufacturer whether these interpretations are accurate. This document is used to verify the description of the term absolute maximum ratings and to request temperature limits if not clearly available in the datasheet.

The first part of the thermal ratings document is used to document the interpretations of the component user and indicate the unavailability of the information in the datasheet (Figure 29).

Absolute Maximum Ratings

To be updated by the component user as interpreted from the datasheet

Definition of the AMR as interpreted by the user		
Operating temperature limit available?		
Storage temperature limit available?		
Temperature location		
Any other temperature used		
Specific information on the temperature location		
	Min (°C)	Max (°C)
Temperature limit values (Operating)		
Temperature limit values (Stoarge)		

Figure 35: Thermal Rating Document – User Interpretation of the AMR

Definition of the AMR as interpreted by the user: The definition the user assumes to be for AMR, directly from the datasheet.

Operating temperature limit available: Indicate if a temperature range with minimum and maximum temperatures is available.

Temperature location: Enter the temperature notation used in the datasheet, such as case, junction, or ambient.

Specific information on the temperature location: Enter more detailed information on the location of temperature estimation, e.g., for the case temperature at the top/center of the package.

The second part of this document has fields to be populated by the manufacturer, indicating whether the interpretations of the user are accurate by entering the data as intended by the manufacturer, as shown in Figure 36.

To be filled by the component manufacturer as intended when requested by the User

Definition of the AMR as intended by the manufacturer		
Temperature location		
Specific information on the temperature location		
	Min	Max
Operating Temperature Limit values		
Storage Temperature Limit values		
Are there any reliability concerns or possibility of damage beyond AMR?		

Figure 36: Thermal Rating Document – Manufacturer Implications for the AMR

Definition of the AMR as intended by the manufacturer: Placeholder for the definition of the AMR title as intended by the manufacturer.

Are there any reliability concerns or the possibility of damage beyond AMR: The manufacturer needs to verify if their definition of the term AMR includes the possibility of damage or reliability concerns beyond AMR.

This document is used as an information-gathering tool to improve the information availability level for the thermal ratings of the device.

Appendix B: Uprateability Assessment Data Collection Document

The form is divided into four sections: the component and its applications, temperature requirements, definitions of the temperatures used, and performance parameters. This document explains the information that is needed and its significance. The relevant definitions are included in the "Introduction" tab to establish an understanding of the terms used in this document.

Component and its Application

Component Type

This section collects information on the type of component being considered for the evaluation. The component type should be specific to use the collected data properly. For example, it is not enough to mention that it is a DRAM component. More information should be provided as to the type of DRAM, e.g., whether it is an Asynchronous DRAM (ADRAM), Synchronous DRAM (SDRAM), or a DDR SDRAM.

Specification

The required specification of the component to be used should be stated (e.g., the memory size and speed). It should also state an acceptable range of these specifications. This level of specificity is required to find the candidates for the pool of components for the uprateability assessment process. Setting specific requirements ensures that the pool of parts considered will contain closely comparable parts.

Application

The application in which the component is to be used. The application should include the product in which the component is to be used and the application of the product. For example, if the product is an airbag control unit, i.e., an electronic control unit used to deploy airbags when a crash occurs, it is the application.

Uprateability Assessment Data Collection

This information relates to the application of a part and they are independent of a part number.

Component and its application:

Component type	
Specification	
Application	
Function in the application	
Mounting location	

Temperature Requirements:

Ambient temperature (°C) for the mounting		
Mounting Location	Minimum	Maximum
0		

Target temperature			
Temperature (°C)	Ambient	Junction	Case
Minimum			
Maximum			

Definitions:

Ambient Temperature:	
Junction Temperature:	
Case Temperature:	

Performance parameters:

Critical Parameters	Units	Allowable value	
		Min	Max
Quiescent current			
Turn on time			
Turn off time			
Turn on and turn off			
On resistance			
Standby current			
...			
...			

The target temperature will never be above the AMR of a given part. Also, the AMR shall be properly converted to the relevant temperature type (e.g., case, junction) with a sufficient safety margin to ensure that we meet the expectations of the IEC definition of AMR.

Figure 37: Uprateability Assessment Data Collection Document

Function

The function of the component within the application is specified in this section. The function helps determine the criticality of the component in the application.

The component's function in an application provides a general sense of the component's load over its lifetime. It can also be used to list the parameters that should be monitored in the component to assess the uprateability of the component. For example, if the data collection is being carried out for a DRAM to be used in an airbag control unit, then the function of the DRAM can be to store real-time data.

Mounting Location

The location where the product would be mounted during operation is required. A specific location is needed to estimate the environmental conditions. For example, if the product is mounted under the hood, it should be stated how far from the engine it is mounted to estimate the thermal load on the product caused by the environment. Similarly, if the product is mounted in the passenger compartment, it should be mentioned where.

Mounting location is essential to identify the environment in which the component would operate. Some common mounting locations for automotive applications are the engine, passenger, or exhaust. If the product is mounted closer to the engine, the ambient temperature would be much higher than if the product is mounted in the passenger compartment. The mounting location would be used to assess the validity of the initial target temperature range for the component and would be an input towards the possibility of thermal management.

Temperature Requirements

In this section, the target temperature is set by assessing the ambient temperature of the mounting location.

Ambient temperature for the mounting location

The mounting locations must be mentioned in the "Uprateability Assessment Data Collection" form, and the corresponding ambient temperatures must be entered.

These values can be based on real-time data or simulation data used as input for the uprateability assessment of the components. These values provide the worst environment possible for the product. Based on these values, the ambient temperature for the components can be estimated. It should be noted that the product's ambient temperature may differ from the ambient temperature of the individual components.

Target Temperature

Target Temperature, as defined in the "Relevant Definitions" section, must be stated with a minimum and a maximum value. These temperatures may be above the recommended operating conditions specified by the manufacturer, but in no case shall they exceed the absolute maximum rating. The target temperature is the desired output for the uprateability assessment process, i.e., the uprateability assessment process tells if the component has the potential to work at the desired target temperature.

Note: Not all temperatures need to be specified. The temperatures should be stated based on the component type.

These values must be reasonably assigned. The target temperature ranges must be defined with respect to either of the following operating temperatures: ambient, case, or junction. A combination of these is also acceptable and desirable. For a fair and easy comparison, all the components from the same category should have the same operating temperatures defined. For example, all the DRAMs should have temperatures defined in terms of the case temperature.

Definitions of the Temperatures Used

The temperatures used in the form should be defined unambiguously. It must be clear how the values are interpreted from the datasheets per the definition.

In addition to the definition, the following points must be mentioned to avoid ambiguity:

- Ambient temperature: it should be clarified if the temperature referred to is of the component or the target assembly.
- Junction temperature: it should be specified what is considered the hottest point on the component, if that is assumed to be the junction temperature location.
- Case temperature: it should be clarified which point on the component is used as a reference.

The operating temperatures must be defined consistently to avoid misinterpretation of the data provided by the manufacturers. All the components being considered for uprateability assessment should be easily comparable; hence, the data from the manufacturer should be accumulated and interpreted similarly.

Note: The temperatures not used in the assessment process need not be defined.

Parameters

This section covers the electrical parameters of a component. Every component is associated with several electrical parameters that are monitored to assess the component's performance. All the critical performance parameters related to the component type are identified and listed here. These parameters are critical to the application in which the component is being used.

In this section, it must be indicated if the parameter is critical to the application and the corresponding acceptable minimum and maximum values. Some common parameters are entered as an example, but this should be an extensive list of all the critical parameters. Therefore, the parameters can be added below the initially mentioned parameters and even overwritten as required. The units should also be noted in the respective column for each parameter.

The "minimum" column refers to the minimum value required for the application. The "maximum" column refers to the maximum allowable value of the parameter for a successful operation. This information would be used to create limits for the uprateability assessment process.

This input would be used to monitor the most critical parameters with respect to temperature for the uprateability assessment process. The critical parameters can be analyzed using the information provided by the manufacturer in the form of curves that show the temperature dependence of the parameters. The parameters would be analyzed with respect to temperature to confirm if they have scope to work beyond the temperatures recommended by the manufacturer. The critical parameters are examined to ensure that the application is carried out successfully and that the component doesn't perform poorly due to high temperatures.

Note: If the target temperature is above the AMR of a given part, that part will not be considered in the pool of candidate parts. Also, the AMR shall be appropriately converted to the relevant temperature type (e.g., case, junction) with a sufficient safety margin to ensure that we meet the expectations of the IEC definition of AMR.

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