ABSTRACT

Title of Document: AN UPRATEABILITY RISK ASSESSMENT METHODOLOGY.

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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 manufacturers' specification range. However, uprating can be an expensive and time consuming process. There is also no guarantee that all parts can be successfully uprated.

In 2002, some electronic part manufacturers began releasing a category of parts considered to be "closer" to military-grade parts, called "Enhanced Plastic (EP)". Since some of the EP parts offer a wider operating temperature range compared with the commercial parts, they are promoted by the EP part manufacturers as an alternative to uprating.

This thesis evaluates the EP parts and finds that when EP parts are available in wider temperature range, they can be beneficial to the electronic system manufacturers as they do not require uprating. However, the availability of EP parts in wide operating temperature range is limited, and the cost is much higher.

The thesis then provides a priori methodology to evaluate the uprateability of an electronic part, and in particular, eliminate parts that are unlikely to be successful in uprating. Four uprateability risk levels are defined which can be determined from the available part and system information during the part selection process. The method of analyzing the information to assign the risk levels is developed for both active and passive parts.

Three case studies of uprateability risk assessment are then presented in the thesis – one for an operational amplifier and two for polymer film capacitors. Complete analysis beginning from manufacturer and part assessment through electrical test results analysis is performed to show the uprateability risk assessment process.

AN UPRATEABILITY RISK ASSESSMENT METHODOLOGY

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
2005

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Dedication

To *my family*, for all of their support and guidance throughout my life.

Acknowledgements

First of all, I am grateful to Prof. Michael Pecht and Dr. Diganta Das for giving me the opportunity to undertake this work. They have been an advisor to me in more ways than just academically. Without their guidance this work wouldn't have been possible. Next, I would like to thank my thesis committee for appreciating and acknowledging my graduate research work. My thanks also extend to Dr. Sanka Ganesan, Dr. Peter Rodgers, Dr. Michael Azarian, and Dr. Keith Rogers for their inputs and suggestions to the thesis.

I am greatly thankful to all my colleagues at CALCE (everyone@calce.umd.edu) for their help and support. My special thanks to Sanjay Tiku for his valuable advice in developing my thesis. My thanks to Anupam Choubey, Anshul Shrivastava, Sony Mathew, Joseph Varghese, Raj Bahadur, Nikhil Vichare, Arindam Goswami, Vidyasagar Shetty, Yuki Fukuda, Shirsho Sengupta, Dan Donahoe, Kaushik Ghosh, Manash Dash, Reza Keimasi, Bin Zhu, and Yuliang Deng for their good company. Also last but not the least, I am certainly indebted to my best friend, Taruna, for her constant support and motivation.

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Chapter 1: Introduction

Electronic parts are most often specified for use in the "commercial" 0 to 70^{o}C, and to a lesser extent in the "industrial" –40 to 85^{o}C operating temperature range. These operating temperature ratings generally satisfy the demands of the dominant customers in the computer, telecommunications, and consumer electronic industries. There is also demand for parts rated beyond the "industrial" temperature range, primarily from the aerospace, military, oil and gas exploration, and automotive industries. However, the demand has not been large enough to attract or retain the interest of major electronic part manufacturers to make these parts. In fact, wide temperature range parts are becoming obsolete and functionally equivalent parts are not replacing them.

1.1 Uprating: Today's Need?

Today, for some applications, it is difficult to procure parts that meet engineering, economic, logistical, and technical integration requirements of product manufacturers that are rated for an extended temperature range (typically beyond 0 to 70^{o}C). There are products to be supported and new products to be built which require parts that can operate at temperatures beyond the "industrial" temperature range. In some applications, the functionality of the product requires that parts with the latest technology and packaging style be used. These parts are often available only in the "commercial" temperature range. If the product application environment is outside the commercial range, steps must be taken to address this apparent incompatibility. For example, oil exploration and drilling applications require small, advanced communication electronics to work underground at high temperatures where cooling is not possible. This is where uprating comes into play. Uprating is defined as a process to assess the capability of a part to meet the functionality and performance requirements of the application in which the part is used outside the manufacturers' specification range [1].

Today, the use of uprated parts is common in many industries. For example, uprated parts are used in telecommunication systems and in flight management and engine control systems. The Boeing 777 uses many uprated parts for its avionics. Even industries such as home appliance or personal computing are facing the need to uprate parts. To mitigate the risks involved in the process, uprating should be performed within the realm of the part selection and management process as shown in Figure 1 [2] [3].

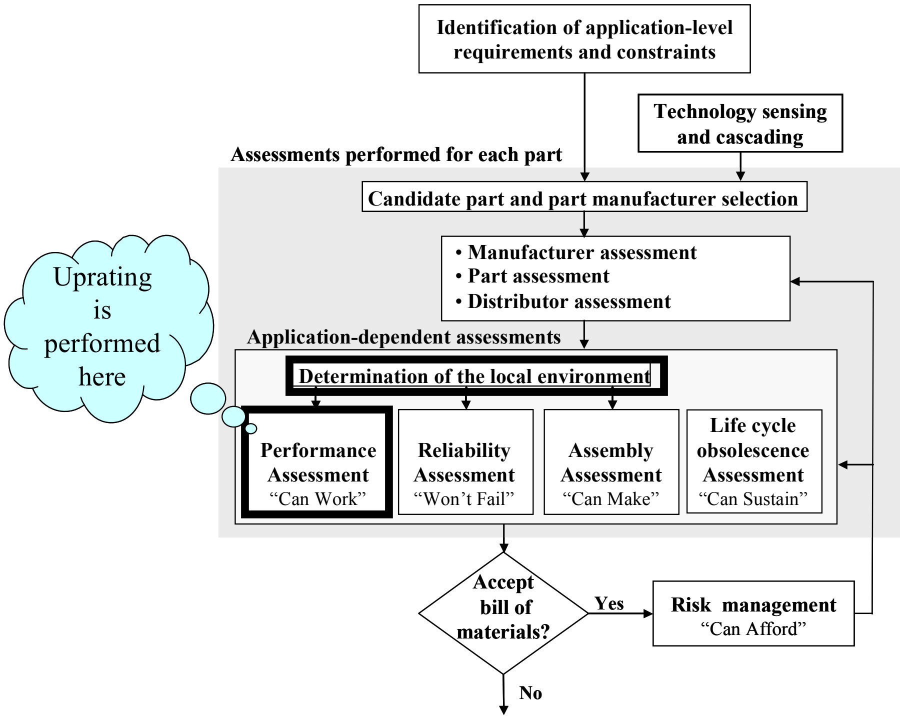

Figure 1: Uprating in the Electronic Parts Selection and Management Process

1.2 Why is Uprating Possible?

Often there is very little difference between parts rated for the various commercial, industrial or even military temperature ranges. In fact, many electronic parts manufacturers have used the same die for various “grades” of parts (commercial, industrial, automotive, and military). For example, Intel [4] stated in their military product data book: “There is no distinction between commercial product and military product in the wafer fabrication process. Thus, in this most important part of the VLSI manufacturing process, Intel’s military products have the advantages of stability and control which derive from the larger volumes produced for commercial market. In the assembly, test and finish operations, Intel’s military product flow differs slightly from the commercial process flow, mainly in additional inspection, test and finish operations[1].”

A review of the reasons why many electronic part manufacturers have discontinued the production of military parts points to business as opposed to technical reasons. For example, when AMD left the military parts business in 1994, it stated “AMD has positioned itself to be a leader in the development and manufacture of integrated circuits for the personal and networked computation and communication sectors. To support this strategy, the decision has been made to begin the active disengagement from the manufacture of military products.” There was no lack of technical expertise in producing the wide temperature range parts but the business plans for the future did not see a significant profit in making such parts.

There is typically a margin between the operating temperature specification of a part and the temperature range over which the part can actually operate reliably. Manufacturers usually provide a margin for this. Margins exist between the specified operating temperature limits and the actual operating capability of the parts. These help to maximize part yield, reduce or eliminate outgoing tests and optimize sample testing

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[1] Intel has stopped supplying military parts (last order date was 12/24/97). However, the statement made by them is still valid in terms of the practice by various manufacturers.

and statistical process control. Mature wafer process lines that produce parts in high volume result electrical parameters within a narrow band. The only difference between the different temperatures rated parts appears to be the additional verification testing of the wider temperature range parts (exploiting the enhanced capability of the robust process). Parts that belong to a robust process with enhanced capability are likely to be able to perform and provide stable and predictable electrical parameters beyond its recommended operating conditions (ROC) ratings.

1.3 Absolute Maximum Rating (AMR)

The absolute maximum rating section in the datasheet includes limits on operational, environmental parameters, including power, power derating, supply and input voltages, operating temperature, junction temperature, and storage temperature. The International Electrotechnical Commission (IEC) [5] defines absolute maximum ratings as "limiting values of operating and environmental conditions applicable to any electronic device of a specific type as defined by its published data, which should not be exceeded under the worst possible conditions. These values are chosen by the device manufacturer to provide acceptable serviceability of the device, taking no responsibility for equipment variations, and the effects of changes in operating conditions due to variations in the characteristics of the device under consideration and all other electronic devices in the equipment.

The equipment manufacturer should design so that, initially and throughout life, no absolute-maximum value for the intended service is exceeded with any device under the worst probable operating conditions with respect to supply voltage variation, equipment component variation, equipment control adjustment, load variations, signal variation, environmental conditions, and variation in characteristics of the device under consideration and of all other electronic devices in the equipment." In other words, the part manufacturers select the AMR values and the companies who integrate electronic parts into products and systems are responsible for assuring that the AMR conditions are not exceeded.

1.4 Recommended Operating Conditions (ROC) Rating

Recommended operating conditions provided by part manufacturers include voltage, temperature ranges, and input rise and fall time. Part manufacturers guarantee the electrical parameters (typical, minimum, and maximum) of the parts only when they are used within the recommended operating conditions and standard operating conditions. Philips notes, "The recommended operating conditions table [in the Philips datasheet] lists the operating ambient temperature and the conditions under which the limits in the "DC characteristics" and "AC characteristics" will be met" [6]. Philips also states that "The table (of recommended operating conditions) should not be seen as a set of limits guaranteed by the manufacturer, but the conditions used to test the devices and guarantee that they will then meet the limits in the DC and AC characteristics table."

ZiLOG [7] states, "Recommended operating conditions are given so customers know the maximum and minimum conditions where normal performance is still available from the device. Once the normal operating conditions are exceeded, the performance of the device may suffer."

1.5 Associating ROC to Reliability

Reliability is the ability of a part to perform within specified performance limits, for a specified period of time, under the life cycle application conditions [8]. Reliability assessment can be performed independent of the performance assessment step (where uprating may be carried out), because the recommended operating conditions that are stated in the part datasheet are associated only to the electrical parameter limits.

It has been observed that the manufacturer's part qualification process is not based on the part's temperature ratings. The part operating temperature ratings are set for performance reasons as opposed to reliability reasons. Part qualification and periodic integrity monitor testing temperature ranges and durations (for tests such as High Temperature Operating Life Test [HTOL], Low Temperature Operating Life Test [LTOL], High Temperature Storage Test [HTS], Temperature Cycle Test [TC], Temperature Humidity Bias Test [THB], Highly Accelerated Stress Test [HAST]) are performed for wafer family and package types. The same temperatures and temperature ranges are used for testing the parts that are sold for various temperature ranges.

Part manufacturers have different opinion on using a part between ROC and AMR limits. Some part manufacturers state that the performance of the part is not guaranteed above the recommended operating conditions. However, they mention that using a part between ROC and AMR does not affect its useful life. These manufacturers do not correlate performance to reliability between ROC and AMR limits of part. Some manufacturers (e.g., Motorola) just state that operating parameters within the recommended operating range are not guaranteed at or near the AMR without a direct reference to reliability. But they add that if the part is used over a long period, they have reliability concerns for useful life [9].

1.6 Associating AMR to Part Performance

The part manufacturers provide absolute maximum rating as limit for reliable operation. Electrical performance of the parts is not related to the AMR conditions. No part manufacturer guarantees the electrical performance at or beyond the AMR. Part manufacturers derive AMRs on parameters as guidance for designers. These values help designers in determining whether the part applications are compatible with anticipated worst-case stress conditions in the equipment. All concerns regarding AMR relate only to the reliability and physical failures of the parts.

ZiLOG [7] states, “AMRs (Absolute Maximum Ratings) are given to allow our customers to understand at what point physical damage can occur to the device under stress. Once the operating conditions exceed the AMR, damage may ensue.” Philips comments, “The ‘RATINGS’ table (Limiting values in accordance with the Absolute Maximum System – IEC 134) lists the maximum limits to which the device can be subjected without damage. This doesn’t imply that the device will function at these extreme conditions, only that, when these conditions are removed and the device operated within the recommended operating conditions, it will still be functional and its useful life won’t have been shortened [6].”

1.7 Summary

The thought process in developing the recommended operating conditions rating relates to the electrical parameter variation with temperature. The word “performance” relates to adherence of the electrical parameters according to datasheet specifications. For example, the gain of a bipolar transistor decreases with increase in temperature and for a CMOS transistor; the transconductance increases with decrease in temperature. The semiconductor physics dictates the changes in electrical parameters with temperature and the part manufacturers determine the limits through testing of parts and provide the guaranteed parameter limits in their datasheets. When the temperature is beyond the ROC (above or below), the parameter limits may go beyond the manufacturer specified limits.

Since the effect of temperature on device parameters depend upon the type of part and the processing technology, it has been observed that in some occasions, the part manufacturers change the parameter limits within ROC with change in processing. For example, Texas Instruments had modified the maximum supply current limit for the UC2950 part from 30mA to 36mA when they changed a fabrication plant [10]. TI states that "the supply current is running higher because the reference zener diode used in the new wafer fabrication plant (SFAB) has a higher breakdown voltage than the zener diode breakdown voltage from the old wafer fabrication plant (MFAB) – hence the bias currents running from it are higher." There is no reference to or implication of this change on the reliability of the part.

Analogously, the AMR conditions relate to the failure mechanisms by which parts fail. At higher temperatures, the time to failure by electromigration decreases and the upper AMR limit may be determined taking the expected life under electromigration failure into consideration. Similarly, at low temperature, the rate of damage by hot carrier injection increases and the lower temperature limit at AMR can relate to the temperature below which the rate of damage accumulation by hot carrier injection become unacceptably high. A complete treatise on the effect of temperature on the failure mechanisms that affect semiconductor parts can be found in reference [11].

The confirmation of ratings of electronic parts is the first step in deciding whether uprating is necessary or possible. The part ratings can be obtained from the datasheet. In spite of having some similarities, the datasheets from different companies vary in parameters, definitions, and level of details. This article focuses on two broad issues about the part ratings, AMR and ROC. This observation helps one to obtain some necessary information. For example, some manufacturers do not provide clear identification of ROC values in the datasheets. Some companies do not specify ROC table in their datasheets, instead they give ROC ambient temperature range in the "ordering information" or "ordering guide" table (e.g., Analog Devices and Maxim Integrated Products). This fact can be confirmed by querying the manufacturers about the temperature range for which they guarantee the electrical parameters. It is evident that there is no standard available for the part ratings. Therefore, it becomes difficult to compare parts of the same functionality from different manufacturers. It also requires extra effort from user to contact manufacturers due to unavailability of some ratings in the part datasheet.

The standardization of part rating can facilitate the methodology of the part selection and management. However, under the current business model of most semiconductor companies, it is unlikely that the manufacturers are going to heed such a call for standardization[2]. It remains incumbent upon the part users to identify the key elements of information and obtain them.

It is important to understand the methodology followed by a part manufacturer to assign the ratings [13]. Since these methodologies are not provided in the datasheet, the part manufacturers should be contacted to gather more information about the ratings.

A part needs to be assessed for uprating when the operation calls for use beyond the ROC conditions. The uprating assessment of a part requires the verification of the electrical performance parameters and functionality over the target application temperature. Reliability assessment of parts should be conducted independent of whether uprating is being performed. The part manufacturers understand the distinction between the AMR and ROC ratings they typically provide both of them to identify and define characteristics of the part at the two ratings ranges. It is needed to understand and exploit the information for making technologically sound decisions on uprating.

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[2] Several JEDEC standards on the contents of a part datasheet exist. In the past, there had been also been standards relating to part datasheet description for specific product types such as HC devices [12]. However, the speed of product introduction and modification makes it impractical to develop and implement the product specifications and standards as in the past.

Chapter 2: Enhanced Plastic Parts: A Viable Alternative To Uprating?

Some electronic part manufacturers have begun to offer a new part category, called "enhanced plastic" parts, which claims to provide several performance, reliability, and logistics advantages over commercial parts. The enhanced plastic parts have been assessed to determine if they are a viable alternative to uprating. This chapter assesses the enhanced plastic parts and compares them with the equivalent commercial parts in terms of availability, recommended operating temperature ratings, electrical parameters, package types, qualification methods, and price.

2.1 Introduction

Prior to the 1980s, military-grade electronic parts accounted for a sizeable portion of purchased electronic parts. However, as the use of electronics in computers, consumer products, and telecommunications increased, many electronic part manufacturers (e.g., Intel, Philips, Motorola, and AMD) decided to quit the military-grade electronic part market. Fortunately, the Perry Directive [53] enabled contractors to use commercial off-the-shelf (COTS[3]) components in military applications, in order to enable state-of-the art technology, advanced functions, reliable components, and lower prices [54] [55]. Nevertheless, in the late 1990s, some part manufacturers (e.g., Texas Instruments, National Semiconductor) begun releasing a category of parts, considered to be closer to military-grade parts, called "enhanced plastic (EP)" [66] [68]. Vishay Intertechnology calls their line of such parts either ruggedized off-the-shelf (ROTS) or military off-the-

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[3] Commercial off-the-shelf (COTS) parts are the catalog products of a part manufacturer intended for commercial applications.

shelf (MOTS). Linear Technology Corporation is in the process of defining similar strategies and product information [65].

In this chapter, the EP line of parts from Texas Instruments (TI) and National Semiconductor (NS) has been analyzed based on their availability, recommended operating temperature ratings, electrical parameters, package types, qualification methods, and price relative to the equivalent COTS parts. The packaging of the COTS and EP parts are generally the same. The statistics are based on information available up to June 8, 2005 at the TI and NS web sites.

There are 387 (356 from TI and 31 from NS) EP parts available, and 162 are scheduled for release from NS. Appendices A and B list the recommended operating temperature range, manufacturer part price (when purchased in quantities of a thousand or more), and price percentage difference between EP and equivalent COTS part.

In its EP portfolio, TI offers digital signal processors, mixed signal and analog parts (e.g., link layer controllers, analog to digital converters (ADCs), digital to analog converters (DACs), comparators, interfaces, operational amplifiers, power management products (PWM), supervisors, timers, voltage reference, and voltage regulators), logic parts (e.g., 36-bit bus transceivers, NAND gates, hex inverters, AND gates, octal bus transceivers, demultiplexers, OR gates, and flip-flops), and memory parts. For logic devices, the parts are categorized by the part technology. Different technologies for EP logic devices include advanced BiCMOS technology (ABT), advanced high-speed CMOS technology (AHC/AHCT), advanced CMOS technology (AC/ACT), high-speed CMOS technology (HC/HCT), low-voltage BiCMOS technology (LVT/LVTH), and low-voltage CMOS technology (LVC/LVCH). All of NS EP offerings belong to mixed-signal and analog group.

2.2 Analysis

The EP part manufacturers suggest that EP parts have various advantages over the equivalent COTS parts [66] [68]. In this section, the features of EP parts [67] [68] have been described and compared with COTS parts.

2.2.1 Controlled Baseline

Controlled baseline means that one assembly, or test site, and one wafer fabrication site is allocated for an EP part to help in logistics [66]. Controlled baseline can also help reduce the time needed for root cause analysis by isolating the source of a problem. Table 1 represents a general comparison of baselines [69] between EP and commercial parts for TI.

It is found that for 9 DSP EP parts for which product location information is available, the assembly site is TI-Philippines Site Code 1510. The equivalent COTS parts are also assembled or tested at the same site, except one COTS DSP, part SM320VC5416HFGW10. This COTS part is assembled at a location operated by a third party under contract with TI. The baseline for each EP part is rigid, while the baseline for the related commercial device may have flexibility. For example, a COTS part can be assembled at more than one facility but an equivalent EP part is stated to be assembled at only one facility [69]. Hence, the EP parts can be easier to trace to source compared to the COTS parts.

Table 1: Comparison of EP and Commercial Baselines [69]

EP Baseline	Commercial Baseline
Wafer fab A	Wafer fab A, B, or C
Assembly test facility Y	Assembly test facility X, Y, or Z
Die M	Die M
Mold compound E	Mold compound E, F, or G
Leadframe K	Leadframe I, J, or K
Bondwire thickness 3	Bondwire thickness 1, 2, or 3
Flow and test programs relative to extended temperature and 10-year operating life	Flow and test programs relative to commercial temperature and market driven operating life expectations

2.2.2 Enhanced Product Change Notification

Enhanced product change notification (PCN) is said to be a feature for the EP parts. If a change is required to a part that impacts the form, fit, or function of that part type, a process change notification is issued. PCNs focus on die revisions, assembly process changes, materials changes (such as mold compound or lead finish), electrical performance, and manufacturing location [67]. There is no example of a publicly issued PCN released only for an EP part but not for the equivalent COTS part by either TI or NS. The policy on PCN for the EP parts is not different compared to the policy of the TI commercial division and both seem to follow the basic JEDEC requirements [81].

2.2.3 Extended Temperature Ratings

In this study, EP parts were compared with their equivalent COTS parts to assess the difference in their ROC temperature ranges. The EP parts for which the ROC temperature ratings are wider than their COTS counterparts are identified as internally uprated in this study. 180 out of 356 TI EP parts are internally uprated. In the NS EP parts (Appendix B), there is no change in the ROC temperatures of EP parts compared to their equivalent COTS part. This means that the NS EP parts are not internally uprated.

For all the EP parts, the electrical parameters in the datasheet are the same as their equivalent COTS parts. Table 2 shows the change in ROC temperature limits of EP parts compared to their equivalent COTS parts. Table 3 shows the availability of TI EP parts over conventional military temperature range (-55°C to 125°C). 50% of available TI EP parts are internally uprated; out of these, 45% of the EP parts have the ROC temperature range of -55˚C to 125˚C. For NS EP parts, there is no difference in the ROC of the EP parts compared to its equivalent COTS parts.

Table 2: Change in ROC Temperature Limits for TI EP Parts

Part	**Total Number of EP Parts**	$EP_{ROC} = COTS_{ROC}$	$EP_{ROC} < COTS_{ROC}$	$EP_{ROC} > COTS_{ROC}$	EP_{ROCH}[4] $> COTS_{ROCH}$	$EP_{ROCL} < COTS_{ROCL}$
DSP	24	11	0	13	1	6
Analog and mixed signal	128	69	2	57	20	10
Logic	200	87	7	106	60	13
Memory	4	0	0	4	0	0
Total	356	167	9	180	81	29

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[4] ROCH: ROC high temperature limit, ROCL: ROC low temperature limit

Table 3: EP Parts Over Conventional Military (-55 to 125°C) Temperature Range

Part	**Total Number of EP Parts**	**EP Parts over -55 to 125°C ROC Temperature Range**	**Number of Uprated Parts**
DSP	24	8	7
Analog and mixed signal	128	29	24
Logic	200	46	45
Memory	4	4	4
Total	356	87	80

2.2.4 Qualification Pedigree

There is no verifiable difference in the testing performed on the EP versus COTS parts[5]. For example, the TI Military Semiconductor Products factsheet for 320VC33's group of digital signal processors, which includes SM320VC33GNMM150 (COTS) and SM320VC33GNMM150EP (EP), explicitly mentions that die size, package, speed, technology, power dissipation, performance, ROC temperature range, package thermal characterization, and weight are identical for these two DSPs. All NS EP parts and their equivalent COTS parts have the same package qualification requirements [75].

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[5] For TI EP parts, qualification data can be obtained only through direct contact after signing a non-disclosure agreement (NDA).

2.2.5 Performance Assurance

Per the definition of recommended operating conditions (ROC), all COTS parts should perform to datasheet specifications if the part is used within the ROC temperature range. TI states that EP parts carry the assurance of TI, not a third party, that the parts will perform to the datasheet specifications [66], suggesting that TI COTS parts may have assurances from a third party, not from TI. This could not be verified in this study because all the COTS datasheets were from TI. TI also promises to provide device analysis and application support in case of failure of an EP part. If EP parts do not perform as defined by the datasheet, TI promises to perform root cause analysis and take appropriate corrective action [76]. As per TI, the failure analysis of a COTS part can be requested by the customer in case of failure of the part [82].

TI states that they warrant performance of the hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed. TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components [77]. TI's statement regarding performance assurance for hardware products is applicable for both EP and COTS parts. The analysis shows that there is no evidence that TI provides some additional performance assurance for EP parts compared to COTS parts.

2.2.6 Part Identification

TI mentions that EP parts have stand-alone datasheets[6]. However, TI provides the same datasheet for two EP digital signal processors [79]. Interestingly, the equivalent COTS parts of these two digital signal processors have different datasheets. The part manufacturers do provide vendor item drawings[7] (VID) for EP parts, which do not come with COTS parts. The VIDs are available on the website for almost all TI EP parts. The VIDs are available for only 12 of the NS EP parts.

2.2.7 Enhanced Obsolescence Management

TI notes enhanced obsolescence management as a potential advantage of EP over COTS parts [66]. TI states that it provides a proactive obsolescence mitigation platform for EP parts. This mitigation strategy includes continuing production of the established baseline after the commercial product has changed, establishing a wafer bank of the current die revision, and/or offering a lifetime buy on the configuration in question [76]. If a proposed change does affect form, fit, function, or reliability, TI commits to minimize the impact on the customer.

In 2003, TI expanded the obsolescence policy for all logic and analog parts, effective immediately that TI will increase the notification time on discontinued logic and analog parts to one full year, followed by a six month period when customers can take delivery [86]. In last nine years, TI provided lifetime buy opportunity for all obsolete parts, irrespective of whether they were COTS or military – grade parts [85]. Interestingly, TI

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[6] Stand-alone implies that each EP part will have an individual datasheet. A stand-alone datasheet of a part is convenient for understanding and analyzing the performance of the part.

[7] The part manufacturers are providing Defense Supply Center Columbus (DSCC) vendor item drawings (VID) for EP parts. For EP parts, DSCC vendor drawings are made available. These drawings generally do not come with COTS parts. Military part numbers are provided with their standardized military drawings (SMD).

provided identical obsolescence mitigation approach of lifetime buy opportunity for the most recent discontinued COTS and military parts [83] [84]. The analysis shows that there is no evidence that TI provides some additional obsolescence management for EP parts (which are considered close to military-grade parts) compared to COTS parts.

2.2.8 Alternative to Uprating

In some cases, the recommended operating temperature ratings of COTS parts are not as wide as the operating temperature of the system and no alternative part or solution exists to get the same functionality and still meet the recommended operating temperature rating of the part. To address this issue, a process termed uprating by Pecht [15], was developed to assess whether a part meets the functionality and performance requirements of the applications for which it is used outside the manufacturer's specification range [16]. More technical details about uprating can be found at [14] – [23]. TI notes that thirty to forty percent of COTS devices are uprated [58]. The electronic part manufacturers generally discourage the practice of uprating [58]-[64]. The offering of some of the EP parts in wider temperature ratings show that some variation of uprating is being performed by the part manufacturers themselves.

2.2.9 Cost-Effective Alternative

For most of the EP digital signal processors (DSPs), the price is about two times higher than their equivalent COTS parts. For most of the TI EP mixed signal and analog parts, the price is about two to three times higher than equivalent COTS parts. For most of the NS EP mixed signal and analog parts, the price is about two to three times higher than their equivalent COTS parts.

The logic EP and equivalent COTS parts, based on the old technologies (AC/ACT, AHC/AHCT, and HC/HCT) are less expensive compared to new technologies parts. The price differential between EP and equivalent COTS parts based on old technologies is high (close to 300-400%). The EP and equivalent COTS parts, based on the newer technology (ABT) are expensive and the price of EP part is closer to the equivalent COTS part. For memory EP parts, the price is more than three times higher than their equivalent COTS parts.

2.3 Conclusions

TI EP parts are available in four categories: DSP, mixed-signal and analog, logic, and memory. For TI, 56% of the parts belong to the logic group, and 36% are mixed-signal and analog devices. There are only 4 EP memory parts out of total 356 available EP parts from TI. All of NS EP offerings belong to mixed-signal and analog group.

The price of EP parts is generally higher than the equivalent COTS parts. EP logic devices are generally three-to-five times more expensive than their equivalent COTS parts. TI comments that their EP logic part pricing cannot be competitive against commercial pricing [30]. For DSPs, the EP parts are about twice as expensive as their equivalent COTS parts. For analog and mixed signal devices, the EP parts are generally two-to-three times more expensive than their equivalent COTS parts.

The EP part manufacturers conduct the same set of qualification and reliability monitor tests for EP and COTS parts. There is no verifiable information regarding any differences in package qualification for EP and COTS parts. The part manufacturers are generally expected to perform root cause analysis and provide failure analysis reports for any parts, irrespective of whether these are EP or COTS. It is found that the benefit of additional performance assurance and obsolescence management associated with EP parts compared to COTS parts is questionable.

Some EP parts offer the feature of wider temperature range. When a part is available at a wider temperature range, then the user does not have to concern with the uprateability of the part, the time and resources needed for uprating. In this study, 47% of total available EP parts (including both TI and NS) are internally uprated. This feature is a benefit to the users.

Chapter 3: Uprateability Risk Assessment Methodology

Part selection and management is a process designed to evaluate and mitigate the risks inherent in the assembly, use and sustainment of electronic parts used in the products and systems. The uprateability risk assessment is a step within the performance assessment process in part selection and management. Uprateability risk assessment is a process to evaluate the risk associated with using a part outside the manufacturer's recommended operating conditions. This process is an evaluation of the possible degree of success in uprating. There is a need to assess parts with available information to determine their uprateability before embarking on detailed analysis and part testing. This chapter describes a methodology for uprateability risk assessment of the electronic parts.

3.1 Introduction

Electronic parts are commonly specified for use in temperature ranges that satisfy the requirements of the personal computer, and consumer electronics markets. In some applications, including telecommunication, automotives, aerospace, military, and oil and gas exploration, the parts need to be used over a wider temperature range. However, the demand for the parts having the ability to operate over a wider temperature range is not sufficient to attract major electronic manufacturers to rate parts in the required range. As a consequence, the equipment manufacturers may not be able to find parts satisfying their temperature range requirements. In this case, some parts are used in wider temperature range beyond their ratings after assessing and reducing the risk associated with the process.

The International Electrochemical Commission (IEC) defines absolute maximum ratings as "limiting values of operating and environmental conditions applicable to any electronic device of a specific type as defined by its published data, which should not be exceeded under the worst possible conditions" [25]. Absolute maximum ratings are provided as a limit for the reliable use of a part [14]. Recommended operating condition are the conditions within which electrical functionality and specifications of the part are guaranteed [14].

Uprating is a process to reduce the risk involved in using components and/or system outside the manufacturer's environmental specifications [14]. More technical details about uprating can be found at [14] – [23]. Prior to uprating, an *a priori* methodology is used to determine need for and/or possibility of success in uprating. This process is called uprateability risk assessment. Uprateability risk assessment process evaluates the risk associated with the use of part outside the manufacturer recommended operating conditions. Uprateability risk level is a number assigned to a part based on the level of risk associated with uprating. The uprateability risk assessment is a cross-functional activity. Component engineering group within an organization is responsible for the uprateability risk level development and assignment. Other groups such as the supply chain, circuit design, and thermal analysis groups provide input to the uprateability risk assessment process. Table 4 shows the responsibilities of different groups involved in the uprateability risk assessment.

Table 4: Functional Groups Contributing to Uprateability Risk Assessment

Group	Overall Responsibilities	Role in Uprateability Risk Assessment
Component engineering	Select parts to meet functional and performance requirements, uprateability risk assessment	Risk level assignment
Supply chain	Perform part and manufacturer assessment, identify discontinued and obsolete parts, maintain the bill of materials	Perform part and manufacturer assessment
Circuit design	Circuit design and simulation, testing	Provide power dissipation of the parts in the system
Thermal	Thermal management of the system, Numerical thermal analysis	Provide system ambient temperature estimates, determine thermal resistances (θ_{JA}, θ_{JC}), estimate junction temperature, collection and analysis of material-dependent thermal parameters

3.2 Uprateability Risk Assessment Methodology

Uprateability risk assessment process is used to evaluate the risk associated with using the part outside the manufacturer's recommended operating temperature ratings. The uprateability risk assessment process is an evaluation of the possible degree of success in uprating, consisting of three steps: data collection, data analysis, and risk level assignment.

3.3.1 Collection of Necessary Information: Step – 1

The information sources include datasheets[8], manufacturer website, assembly guidelines and application notes, and direct contacts with part and system designers. Adequate time must be allocated for the collection and analysis of information. Table 5 shows information required for the uprateability risk assessment of an electronic part.

Table 5: Necessary Information for Uprateability Risk Assessment

Part Information	Absolute maximum rating (AMR) temperature	Junction (T_{JAMR}), case (T_{CAMR}), and ambient temperatures (T_{AAMR})
	Recommended operating condition (ROC) rating temperature	Junction (T_{JROC}), case (T_{CROC}), and ambient temperatures (T_{AROC})
	Power dissipation	Maximum power dissipation of the part in system (P_S)
	Thermal resistance	Junction-to-ambient (θ_{JA}), junction-to-case (θ_{JC})
	Conditions of operating life tests	High temperature operating life test temperature (T_{HTOL})and low temperature operating life test temperature (T_{LTOL})
System Information	System ambient temperatures	Maximum (T_{ASMAX}) and minimum temperatures (T_{ASMIN})

Junction-to-ambient or junction-to-case thermal resistance[9] is used to estimate the operating junction temperature based on maximum power dissipation of the part during

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[8] Each product has different datasheets based on the stage of product including pre-production datasheets, preliminary datasheets, and final datasheets [24].

[9] JEDEC [32] defines the thermal resistance as, "the temperature difference between two specified points or regions divided by the power dissipation, under conditions of thermal equilibrium". For the semiconductor devices, the thermal resistance is "a measure of the ability of its carrier or package and mounting technique to provide for heat removal from the semiconductor junction" [14].

the application. If the thermal resistance value is not available for a part, it is selected from another part manufacturer for the same package type. Most commercially available packages correspond to industry standard configuration and thermal resistance values for same package types do not vary significantly across different manufacturers[10]. The conservative (i.e., higher) values of thermal resistances are used in estimating the operating junction temperature. Also, the uprateability risk assessment methodology is performed at part level followed by testing of the part (in some cases), not at board or system level for which numerical thermal analysis and system characterization are performed [20]. The use of thermal resistance values for initial risk level assignment is acceptable.

High temperature operating life (HTOL) test is used as a qualification or reliability monitor test. Typical ambient temperatures of 125°C to 150°C are used for duration of up to 1000 hours. Low temperature operating life (LTOL) test is the analogous test performed at low temperature (commonly at ambient temperature of -55 to -65°C). In some cases, the part is monitored for the functionality during operating life tests. In other cases, the electrical measurements are performed before and after the operating life tests. The test temperature in any of these two test schemes are used in the uprateability risk assessment methodology for comparison with the estimated operating junction temperature. However, the operating life test condition can be used as AMR limit (if unavailable), if the part is monitored for the functionality during the test.

The maximum power dissipation of part in the system is also used to conduct the uprateability risk assessment. The power dissipation of a part in the system is different

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[10] Texas Instruments notes the junction-to-case thermal resistance value for SOIC package with 8 leads as 39.4 [27]. Fairchild provides the junction-to-case thermal resistance value as 39.9 for this package [28].

from power dissipation that is mentioned in the datasheet of part. The power dissipation value of a part provided in the datasheet is the capability of package to dissipate heat [14]. The power dissipation of the part in the system is application dependent. The power dissipation value of a part in the system is provided by the circuit design team to estimate the operating junction temperature.

For passive parts (e.g. capacitors, resistors, inductors), the AMR temperature rating is generally not provided by the manufacturers. The material dependent thermal parameter is used as an estimate for the AMR rating of the passive parts. These thermal parameters are the temperatures at which the parts either can not function at all or most likely show degradation in the performance. The reasons can be change in the state of the material (e.g., solid to liquid, liquid to gas) or change in crystalline morphology of the material (e.g., Curie point, temperature of maximum crystallinity of dielectric). The selection of material related thermal parameter is technology-driven. For resistors, the manufacturers provide 100% derating temperature which can be used as AMR limit. High temperature life (HTL) test is used to study the effect of elevated temperature, typically at maximum rated-condition of temperature and voltage for the extended period of time usually 1000 hours. Low temperature life (LTL) test is used to study the performance of part at low temperature. Table 6 shows the material related thermal parameters which can be used as AMR estimate in the uprateability risk assessment of passive parts.

Table 6: Typical Absolute Maximum Rating (AMR) Estimates for Passive Parts

Category	Sub-category	Temperature related material property
Non-polar capacitors	Film	Melting point of dielectric, temperature of maximum crystallinity of dielectric, any known transition temperature
	Ceramic	Curie point of dielectric
Polar Capacitors	Wet electrolytic	Evaporation temperature of electrolyte, freezing point of electrolyte
	Solid electrolytic	Melting point of electrolyte
Magnetic	Ferrite core	Curie point of ferrite material
	Ceramic core	Curie point of ceramic material

3.3.1 Analysis of Information: Step – 2

The maximum operating junction temperature is estimated using the equation:

$$T_{JMAX} = T_{ASMAX} + \theta_{JA} * P_S \qquad (1)$$

where θ_{JA} is junction-to-ambient thermal resistance of the part, P_S is the maximum power dissipation of the part in the system, and T_{ASMAX} is maximum ambient temperature of the system. If θ_{JA} is not available, θ_{JC} can be used instead. The maximum operating junction temperature is estimated using the equation:

$$T_{JMAX} = T_C + \theta_{JC} * P_S \qquad (2)$$

where θ_{JC} is thermal resistance from junction-to-case. The maximum estimated operating junction temperature is compared with AMR and ROC junction temperature values. If junction temperature can not be calculated due to unavailability of thermal resistance, maximum ambient temperature of system is compared with AMR and ROC ambient temperature limits. The use of equations 1 and 2 is acceptable for the estimation of operating junction temperature in the uprateability risk assessment.

3.2.3 Uprateability Risk Level Assignment: Step – 3

Four uprateability risk levels are defined which can be determined from the available part and system information during the part selection process. The risk levels indicate the uprateability of parts. The parts with risk level four are deemed inappropriate for uprating and the parts with risk level two and three are recommended for the complete uprating assessment including electrical testing. Parts with risk level one are possible to use in a system without any additional analysis or testing. Table 7 defines the risk level along with their significance.

Table 7: Four Risk Levels in Uprateability Risk Assessment

Risk Level	Significance
1	Part does not need to be uprated
2	There is high chance of success in uprating
3	There is low chance of success in uprating[11]
4	Part can not be uprated

Figure 2 shows the flow chart for uprateability risk level assignment at high temperature end. There are slightly different steps in the flow chart for uprateability

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[11] The difference between risk level 2 and 3 is limited to the availability of industrial (or wider) temperature range parts of same functionality and technology, and HTOL and LTOL test conditions.

assessment at low temperature end, where LTOL test condition is used. Also, the operating junction temperature is not estimated at low temperature end. There is cold start issue involved with low temperature application. Cold start means that device begins to operate at low temperature. Since device is in the thermal equilibrium with the environment at the moment of start, the temperature of junction is the same as ambient.

The parts with risk level four can not be uprated and are replaced by alternative parts. The parts with risk level one do not need to be uprated and can be used without testing. The parts with risk level two and three are recommended for electrical testing over the temperature range of interest. The datasheet provides electrical characteristics of the part over ROC temperature rating. The electrical parameters of a part are measured at different temperatures. The maximum and minimum limits of electrical parameters (provided in the datasheets) are not changed when the part is uprated using parameter conformance method. The electrical parameters can be assigned new specification limits (if necessary), when the part is uprated using parameter re-characterization method.

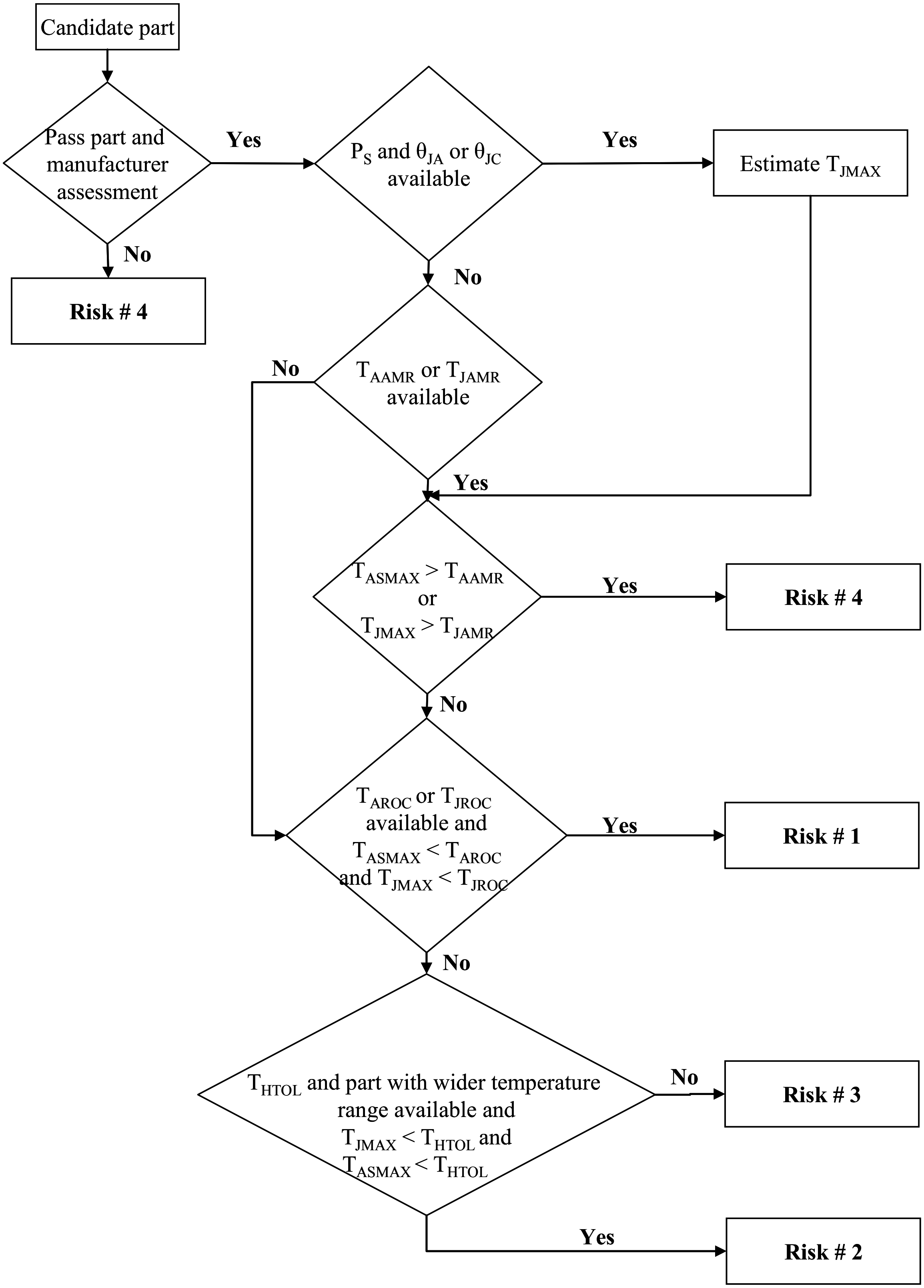

Figure 2: Uprateability Risk Assessment Flow Chart at High Temperature End

3.3 Summary

The methodology for uprateability risk assessment of electronic parts has been developed. The parts with risk level four can not be uprated and are replaced by alternative parts. The parts with risk level one do not need to be uprated and can be used without testing. The parts with risk level two and three are recommended for electrical testing over the temperature range of interest. The methodology determines the uprateability of electronic parts and eliminates parts with risk level one and four for uprating.

Chapter 4: Uprateability Risk Assessment Case Study - I

The case study was conducted to assess the list of parts for Modular Avionic Control (MAC) system for uprateability. The system manufacturer provided the list of parts with maximum system ambient temperature (-55°C to 115°C) and maximum power dissipation of the parts in the system. The list contained 153 active parts. The datasheets, application notes, and operating life tests conditions of all parts were collected and analyzed. The thermal ratings and thermal resistance values were documented.

4.1 Collection of Necessary Information: Step - 1

50% of parts (76 of 153) have only AMR thermal ratings. 23% of parts (36 of 153) have only ROC thermal ratings. 26% of parts (40 of 153) have both AMR and ROC thermal ratings. About 14% of parts (21 of 153) have identical AMR and ROC thermal ratings. Appendix C shows the diversity in availability of thermal ratings.

Thermal resistance values were gathered from several resources including datasheets, manufacturer websites, and direct contacts with part and system designers. The thermal resistance values could not be gathered for 38% of parts (59 of 153). For 23% of parts (43 of 153), only junction-to-ambient thermal resistance value could be obtained. For 7% of parts (11 of 153), only junction-to-case thermal resistance value could be gathered. For 26% of parts (40 of 153), both junction-to-ambient and junction-to-case thermal resistance values could be obtained. Appendix D shows the diversity in thermal resistance information.

There is inconsistency in availability of information in the datasheets. There is need for standardization of the information in the datasheets. Conservative engineering judgments are made in the cases where information is not available. The standardization of part ratings can facilitate the methodology of uprateability risk assessment. 50% of parts (76 of 153) have only AMR thermal ratings. 23% of parts (36 of 153) have only ROC thermal ratings. 26% of parts (40 of 153) have both AMR and ROC thermal ratings. About 14% of parts (21 of 153) have identical AMR and ROC thermal ratings.

4.2 Analysis of Information: Step – 2

The operating junction temperature of parts was estimated when the thermal resistance and power dissipation values were available. For example, Texas Instruments (TI) part TL072ID, an operational amplifier, has junction-to-ambient thermal resistance value of 165.5°C/W, obtained from TI's thermal database. The operating junction temperature is estimated to be 146°C using equation 1 based on the maximum power dissipation value provided by the system manufacturer.

4.3 Uprateability Risk Level Assignment: Step – 3

The part and manufacturer assessment were conducted based on the developed guidelines [30]. The part assessment categories include average outgoing quality (AOQ), process capability index (C_{pk}), integrity monitor test results, and assembly guidelines. TI's part, TL072ID passed the part assessment. Table 8 shows the part assessment results [30].

Table 8: Part Assessment of TL072ID

Part Assessment Categories and Results			
Average Outgoing Quality (AOQ)[12] (ppm)	Cpk	Integrity monitor test results	Assembly guidelines
3 – Passed	3 – Passed	Passed	Passed

The manufacturer assessment categories include process control, handling, storage and shipping control, corrective and preventive action, product traceability, and change notification. TI passed the manufacturer assessment. Table 9 shows the manufacturer assessment results [21].

Table 9: Manufacturer Assessment of Texas Instruments

Manufacturing Assessment Criteria and Results				
Process control	Handling, storage, and shipping control	Corrective and preventive action	Product traceability	Change notification
Passed	Passed	Passed	Passed	Passed

Texas Instruments (TI) part TL072ID, an operational amplifier, is assigned risk level 2 based on the methodology since the high temperature operating life (HTOL) test temperature is 150°C. Also, another part TL072MUB is available over the wider temperature range of -55°C to 125°C. It signifies that there is high chance of success in uprating of the part TL072ID. This part was recommended for electrical testing.

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[12] Average outgoing quality or AOQ is defined as the total number of parts per million that are outside manufacturer specification limits (outside the LSL and USL, the lower and upper specification limits) during the final control inspection. Manufacturers conduct visual, mechanical, and electrical tests to measure AOQ.

4.4 Uprating of Risk Level 2 Operational Amplifier

TI's operational amplifier TL072ID was assigned uprateability risk level two. Fifty TL072ID were tested at three temperatures (-65, 25, and 125ºC). Several parameters were measured including supply current, input offset voltage, input offset current, input bias current, maximum peak output voltage, large-signal differential voltage amplification, and common-mode rejection ratio. For 49 parts, all electrical parameters are within the datasheet specified limits at three test temperatures. For 1 part, input bias current value (22.9 nA) is outside the datasheet specified limit (20 nA) at 125ºC [31]. Table 10 shows the 6σ spread for input bias current of TL072ID at three test temperatures.

Table 10: Characterization Curve for Input Bias Current of TL072ID (Sample size = 49 parts)

Test temperature (°C)	Mean + 3σ (nA)	Mean - 3σ (nA) (Ignoring negative values)
-65	0.961	0
25	0.059	0
125	21.028	0

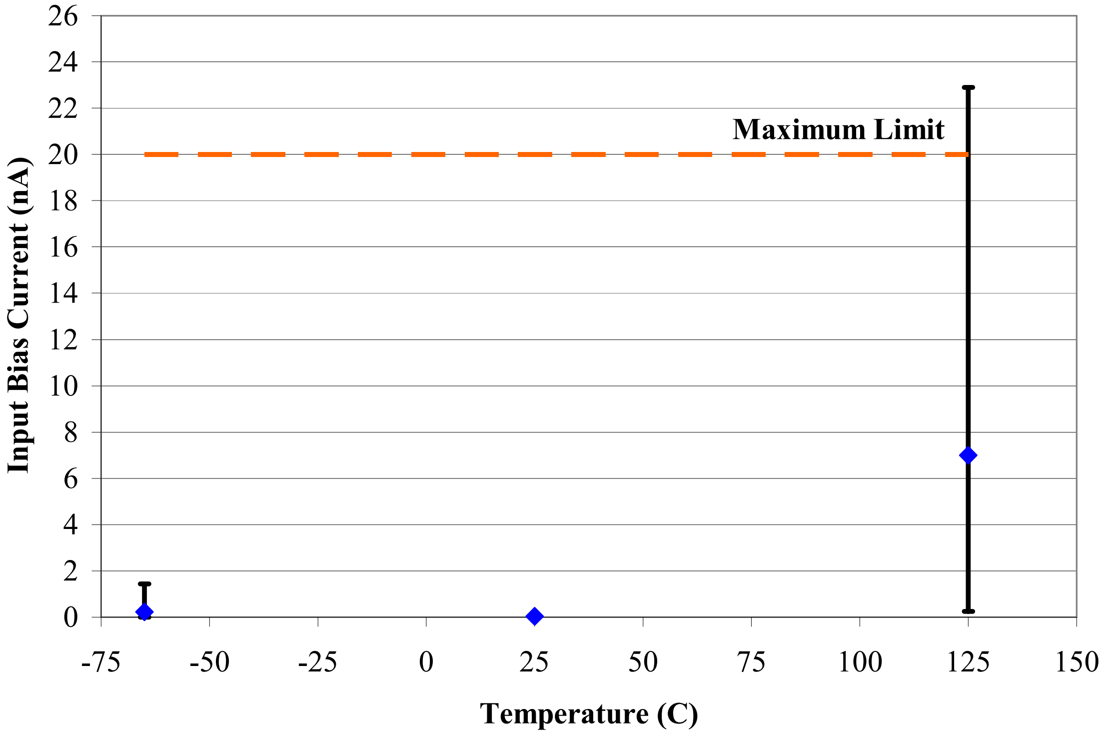

Figure 3: Input Bias Current vs. Temperature (Sample size = 50 parts)

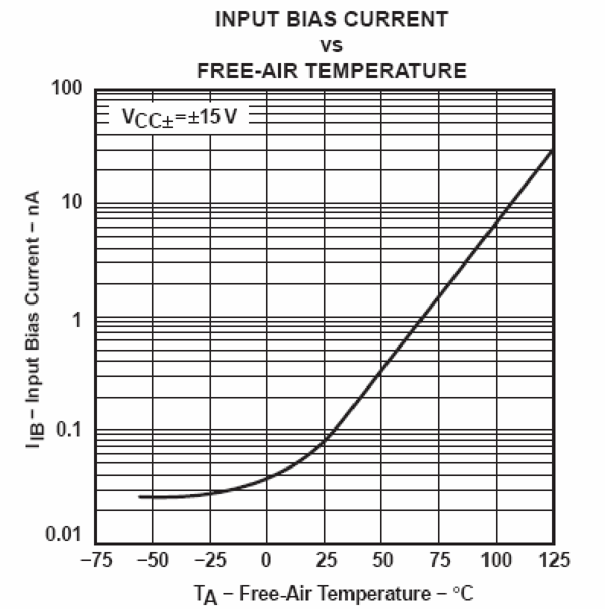

Figure 4: Input Bias Current versus Temperature (from datasheet [31])

Figure 3 shows the change in input bias current with temperature based on experimental results. Figure 4 shows the change in input bias current of TL072ID with ambient temperature obtained from datasheet. The input bias current at 125°C is 30 nA from the curve provided by the manufacturer [31]. Also, the maximum input bias current for the wider temperature range part, TL072MUB (-55 to 125°C) is 50 nA [22]. The input bias current values at 125°C for all 50 samples are within the maximum specified limit (30 nA) provided by the manufacturer's datasheet. The electrical specifications are not changed because all parameters are within the manufacturer's specified limits. It is concluded that TL072ID is uprateable and has been uprated from ROC rating of -40 to 85°C to -65 to 125°C using parameter re-characterization.

4.5 Uprateability Risk Classification: Based on Technology and Part Type

The parts were assigned uprateability risk level based on the methodology. The parts were grouped based on technology after the uprateability risk level assignment. The parts were grouped in three categories: MOS, bipolar, and BiCMOS. The technology of 19 parts could not be verified. The parts were also grouped based on part type: analog, digital, and mixed-signal. Table 11 and Table 12 show the risk level classification based on technology and part type respectively. Parts with risk level two and three are recommended for testing. Appendix E lists the parts with uprateability risk level two and three.

Table 11: Uprateability Risk Classification Based on Technology

Technology	Total parts	Risk # 1	Risk # 2	Risk # 3	Risk # 4	Decision could not be made
MOS	63	18	25	5	11	4
Bipolar	67	27	12	5	13	10
BiCMOS	4	0	1	0	3	0
Not verifiable	19	12	2	0	0	5
Total	153	57	40	10	27	19

Table 12: Uprateability Risk Classification Based on Part Type

Part type	Device	Total	Risk#1	Risk#2	Risk#3	Risk#4	Decision could not be made
Analog	Amplifier	13	4	2	2	5	
	Current driver	2	2				
	Diode	13	10	1	1		1
	Filter	1				1	
	MOSFET	14	8	2	1	2	1
	Oscillator	14	11	1			1
	Power driver	5	5				
	Power MOSFET	1	1				
	Rectifier	10	3	1	1	4	1
	Register	1	1				
	Suppressor	7					7
	Switch	1			1		
	Transformer	2					2
	Transistor	7	3	4			
	Voltage reference	5		3		2	
	Voltage regulator	3		1		2	2
	Total	100	48	15	6	16	15
Digital	AND-Gate	11	3	8			
	Controller	1		1			
	CPLD	2			2		
	EEPROM	2		2			
	Flip-Flop	6	1	5			
	Inverter	6	1	3			2
	Memory	1				1	
	Microprocessor	2				1	1
	SRAM	2		1	1		
	Total	33	5	20	3	2	3
Mixed-signal	Comparator	4	2	1	1		
	Converter	4		1		3	
	Multiplexers	4				4	
	PWM Controller	1				1	
	Sensor	2	1				1
	Transceiver	5	1	3		1	
	Total	20	4	5	1	9	1

4.6 Conclusions

The methodology for assessing the uprateability of electronic parts has been demonstrated and validated for an operational amplifier. TI's operational amplifier TL072ID is assigned uprateability risk level 2 and hence tested over the temperature range of interest. The experimental results show that the operational amplifier is uprateable and has been uprated from ROC rating of -40 to 85°C to -65 to 125°C using parameter re-characterization. The experimental results validate the methodology that there is high chance of success in uprating of uprateability risk level two part.

Chapter 5: Uprateability Risk Assessment Case Study - II

The case study was conducted to assess one polymer film capacitor for uprateability which constitutes the Modular Avionic Control (MAC) system. The system manufacturer provided the maximum and minimum system ambient temperatures (-55°C to 115°C).

5.1 Capacitor Terminologies

Capacitors can be represented by a generalized model shown in Figure 5. In this model, C is the primary capacitance, R_L is the insulation resistance (IR), R_s is the equivalent series resistance (ESR), DA is the dielectric absorption (DA), and L is the equivalent series inductance (ESL). In Figure 5, dielectric absorption has been modeled as a capacitor (C_{DA}) connected in series with a resistor (R_{DA}). The capacitance of the capacitor will depend on temperature, humidity, voltage and time.

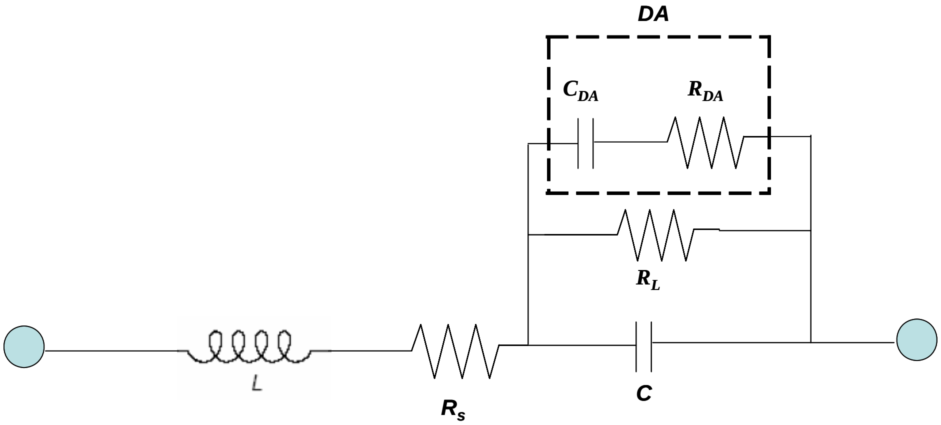

Figure 5: Equivalent Electrical Model for Capacitors

The insulation resistance (IR) is a measure of the capability of a material to withstand leakage of current under a DC voltage gradient. Insulation resistance governs the leakage of current through a capacitor. The IR is dependent on the dielectric molecular structure and chemical composition. The dielectric thickness has only a minor influence on it. The manufacturers specify a maximum IR along with capacitance value as IR × C.

Dielectric absorption is the property of a dielectric which prevents a capacitor from totally discharging, even when short-circuited for a short period of time. Dielectric absorption (DA) is also called "soakage" or "voltage retention". A charged capacitor retains part of the charge, even after being discharged (shorted for some number of seconds), as if it had "soaked" into the dielectric. This is due to the polarization in the insulating material and the dielectric. The charge absorption effect is caused by a trapped space charge in the dielectric and is dependent on the geometry and leakage of the dielectric material [49]. Due to dielectric absorption, the capacitor has a small voltage (i.e. regained voltage) on its terminal wires, within seconds or minutes. The dielectric absorption[13] is calculated as the ratio of regain voltage to charging voltage and represented in percentage. The dielectric absorption is more pronounced at high temperatures. In general, teflon, polystyrene, and polypropylene are the best (as low as 0.02%), while the electrolytics, high-k ceramics, and oil-filled are the worst (1% on up).

The equivalent series resistance (ESR) represents the minimum impedance value for a capacitor. The main (if not only) limiting factor in high-frequency performance (in switching power supplies, for example) for large filter capacitors is the equivalent series resistance or ESR. The ESR depends on the capacitor working voltage. The

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[13] The dielectric absorption DA can be calculated according to the following formula: DA = U1 / U2 x 100%, where DA is the dielectric absorption, U1 is the regained voltage, and U2 is the charging voltage.

ESR is also dependent on capacitor shape. Film capacitors used to have lower ESR than any of the electrolytic capacitor.

The dissipation factor or tanδ is the ratio of the real (active) to the imaginary (reactive) parts of the impedance of the capacitor. The impedance primarily consists of equivalent series resistance, equivalent series inductance, and the capacitance. The equivalent series resistance and the capacitance contribute to the reactive part of the impedance whereas the active part is the equivalent series resistance. Ideally, the dissipation factor is zero. Higher values of dissipation factor are undesirable as they indicate greater power losses leading to a shorter life at elevated temperatures [38].

The dissipation factor is a function of metal losses, dielectric losses and insulation resistance. The metal losses include losses due to the lead resistance, end terminations and metal foil/film. The dielectric losses are a result of the frictional heat due to oscillations of the particles in the dielectric; the oscillations being a consequence of the changing polarization of the particles caused by alternating fields. The insulation resistance is usually a small component of the dissipation factor.

5.2 Polyethylene Terepthalate (PET) Film Capacitor

Film capacitors use dielectrics that are polymer-based compounds, including polypropylene, polycarbonate and polyester. Polyester has traditionally been the primary dielectric materials in the film capacitor industry. The most commonly used polyester film dielectric is Polyethylene Terepthalate (PET). PET dielectric is available under different names (such as Mylar of DuPont). Because of large consumption volumes, the price per pound of PET film is less expensive than the other alternatives. That translates into a lower price for the PET film chip when compared to other film chip dielectrics. The capacitance values in the PET film chip are the largest of all the film chips, reaching into the tens of microfarad range [52].

The PET capacitor under consideration is of metallized film type. In metallized film capacitor, the metal layer is vacuum deposited on the dielectric surface and the interconnections are made as shown in Figure 6 [35]. This metal deposition replaces the conventional metal foil conductive plate used in a standard film-foil capacitor. The metallized film capacitors show a distinct advantage over the non-metallized parts in terms of size and weight savings and possess self-healing properties. When the electric field strength is high (>50 KV/cm), a current flows and increases rapidly due to avalanche effect. This effect is called flash-over. The electric field strength which an insulator can withstand before flash-over occurs is called the dielectric strength. In case of a flash-over of metallized film capacitor, the very thin aluminum film instantaneously evaporates, insulating the damage area. Every flash-over of the capacitor will therefore not destroy the capacitor, but will just produce a minor reduction of the electrode area (reduction of capacitance) [43].

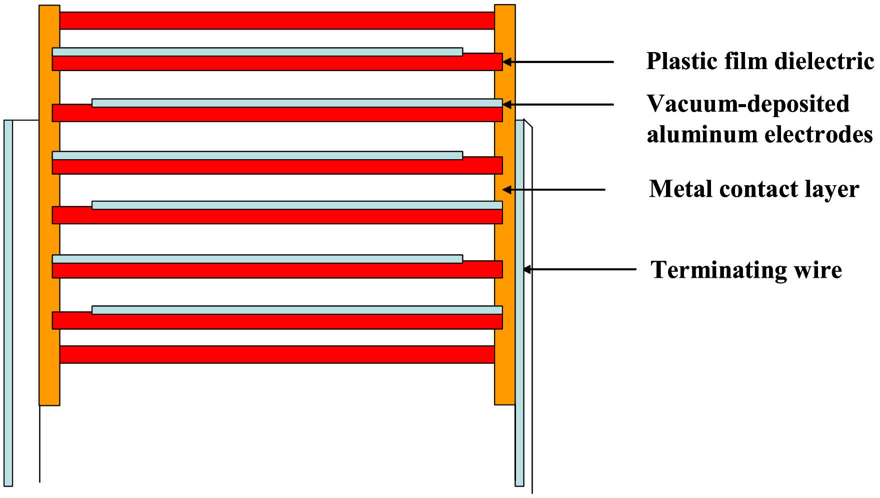

Figure 6: Construction of a Metallized Film Capacitor [35]

The electrical characteristics of PET dielectric are stable below 160°C. It has a melting point of 254°C with temperature sensitive electrical properties [37]. The PET film provides capacitance values in high range (up to 10 uF) along with availability in small size. Table 13 shows the properties of PET film.

Table 13: Properties of PET Film [40]

Property	PET
Dielectric Constant	3.0 ~ 3.3
Dielectric Loss (%)	0.2 ~ 0.5
Breakdown Voltage (kV/mm)	150 ~ 200
Melting Point (°C)	260
Water Absorption	0.3 ~ 0.4

The capacitance of the PET capacitors has a positive temperature coefficient. The temperature drift varies between -10% to +15% between -55°C to 125°C. The capacitance starts to decrease with frequencies beyond 1 KHz and decreases by around 3% at 1 MHz. The main factor for the variation of the capacitance is the variation of the dielectric constant/permittivity of the material dielectric. Figure 7 shows the change in dielectric constant of PET film "Mylar" with temperature [87].

The dissipation factor of PET capacitor is less than ~1.0% at 1 KHz. The dissipation factor shows a +2% maximum variation with temperatures up to 125°C. It increases continuously from 50°C and is a potential problem at higher temperatures. Below 50°C, the change in dissipation factor is not monotonic. The dissipation factor shows an increase to about 3% with frequencies of about 100 KHz [33], [36].

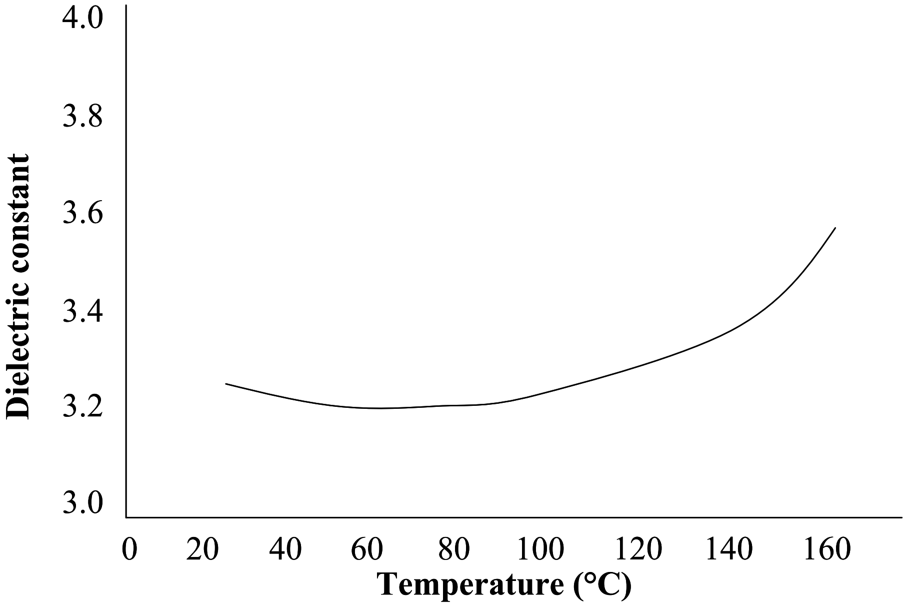

Figure 7: Change in Dielectric Constant of PET film "Mylar" with Temperature

5.3 Uprateability Risk Assessment of Polyethylene Terepthalate (PET) Film Capacitor

The PET film capacitor constitutes the Modular Avionic Control (MAC) system. The system manufacturer provided the maximum and minimum system ambient temperatures (-55°C to 115°C).

5.3.1 Collection of Necessary Information: Step – 1

The polymer film capacitor selected for the uprateability risk assessment is of metallized film type with Polyethylene Terepthalate (PET) as dielectric material. The polymer capacitor under investigation had a nominal capacitance of 10 uF at 1 KHz, ROC temperature rating of -55ºC to 85ºC (without any voltage derating), voltage rating of 100V, maximum dissipation factor value of 1% at 1 KHz, and a capacitance tolerance of ± 10%. The voltage is derated to 50V at 125ºC. There is no AMR temperature rating provided for the part. The melting point (254°C) and temperature of maximum crystallinity (160°C) of PET dielectric were obtained as material dependent thermal parameters. The manufacture conducts the high temperature life test at 85°C (T_{HTL}) for 1000 hours.

5.3.2 Analysis of Information: Step – 2

For PET capacitor, there are two thermal parameters available: melting point (254°C) and temperature of maximum crystallinity (160°C). The temperature of maximum crystallinity is considered as the AMR estimate in the uprateability risk assessment as it is more conservative than the melting point.

5.3.3 Uprateability Risk Level Assignment: Step – 3

The part and manufacturer assessment were conducted based on the developed guidelines [30]. The part assessment categories include average outgoing quality (AOQ), process capability index (C_{pk}), integrity monitor test results, and assembly guidelines. ITW Paktron's part, 106K100CS4G passed the part assessment. Table 14 shows the part assessment results [30].

Table 14: Part Assessment of 106K100CS4G [88]

Part Assessment Categories and Results			
Average Outgoing Quality (AOQ) (ppm)	C_{pk}	Integrity monitor test results	Assembly guidelines
3 – Passed	1.01 – Passed	Passed	Passed

The manufacturer assessment categories include process control, handling, storage and shipping control, corrective and preventive action, product traceability, and change notification. ITW Paktron passed the manufacturer assessment. Table 15 shows the manufacturer assessment results [30].

Table 15: Manufacturer Assessment of ITW Paktron [89]

Manufacturing Assessment Criteria and Results				
Process control	Handling, storage, and shipping control	Corrective and preventive action	Product traceability	Change notification
Passed	Passed	Passed	Passed	Passed

ITW Paktron part 106K100CS4G, a PET film capacitor, is assigned risk level 3 based on the methodology since the high temperature life (HTL) test temperature is 85°C which is less than the system ambient temperature (115°C). Also, another part over the wider temperature range than ROC temperature rating of 106K100CS4G is not available. It signifies that there is low chance of success in uprating of PET capacitor. This part was recommended for electrical testing.

5.4 Uprating of Risk Level 3 PET Capacitor

ITW Paktron's film capacitor 106K100CS4G was assigned uprateability risk level three. Ten PET capacitors were tested over the temperature range of -70ºC to 155ºC with varying DC bias voltage (0, 50, and 100V) and frequency (0.1, 1, and 10 KHz). The capacitance and dissipation factor were measured.

The capacitors were tested using an external voltage bias fixture, coupled to an LCR meter and voltage source. The LCR meter was compensated for open and short corrections using the same length of wire used for each capacitor. A control sample from each group was tested at zero DC bias with different frequencies to formulate the experimental plan. The capacitance and dissipation factor were measured at different temperatures by changing the DC bias voltage and frequency. Temperature was controlled by Temptronic Thermal Control equipment.

The capacitors were tested initially at 25ºC. Subsequently, the capacitors were tested at -55ºC and -70ºC respectively. Later on, the capacitors were brought back to 25ºC. Subsequently, the capacitors were tested at 85ºC, 125ºC, and 155ºC respectively.

After the experiment, the average values of capacitance and dissipation factor were determined. The results were compared to the capacitance and dissipation factor values provided in the datasheet. The maximum and minimum limit values were calculated using the tolerance value (±10%) provided in the datasheet of the PET capacitor.

5.4.1 Effect of Temperature on Electrical Characteristics of PET Capacitor

Figure 8 shows the effect of temperature on the capacitance at 100V (100% rated voltage) and 1 KHz (datasheet test frequency)[14]. The capacitance has the positive temperature coefficient over the temperature range of -70ºC to 155ºC. At 125ºC, the average capacitance value (11.04 uF) is slightly outside the manufacturer's specified maximum limit of 11 uF. The average capacitance value is beyond the manufacturer's specified maximum limit of 11 uF at 155ºC.

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[14] The manufactures generally provide the electrical parameters values for a capacitor at constant frequency and temperature. For PET capacitor under investigation, the manufacturers provide electrical parameters values at 1 KHz without any mention of test temperature.

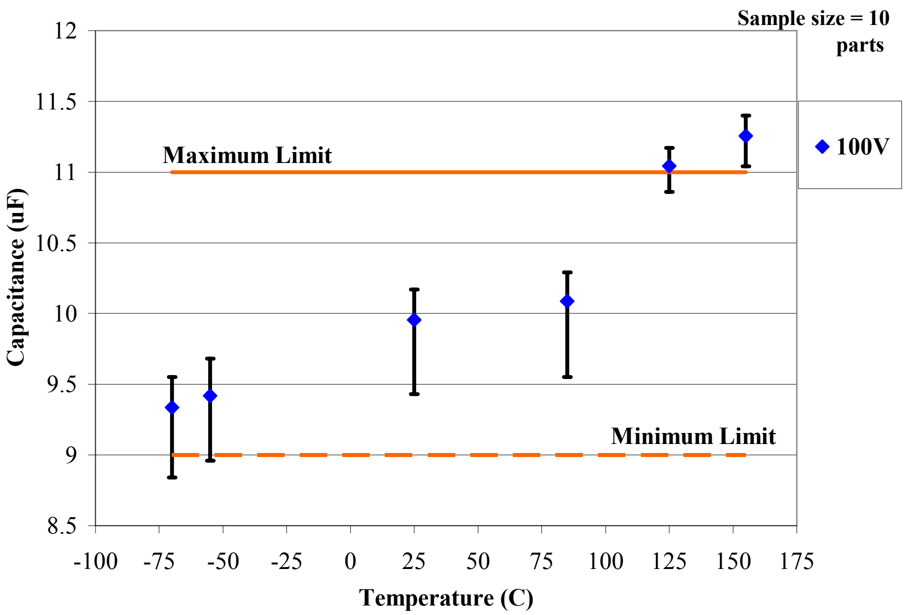

Figure 8: Effect of Temperature on Capacitance of PET Capacitor (Sample size = 10 parts)

Figure 9 shows the percentage deviation of capacitance from the nominal value (10 uF) over the temperature range of -70ºC to 155ºC. It shows the temperature dependency at 1 KHz (datasheet specified test frequency) and three DC bias voltage conditions (0V, 50V, and 100V). The capacitance values are outside the maximum specified limit for capacitance above 125ºC for all voltages. Table 16 shows the 6σ spread for capacitance of the PET capacitor at 100V and 1 KHz.

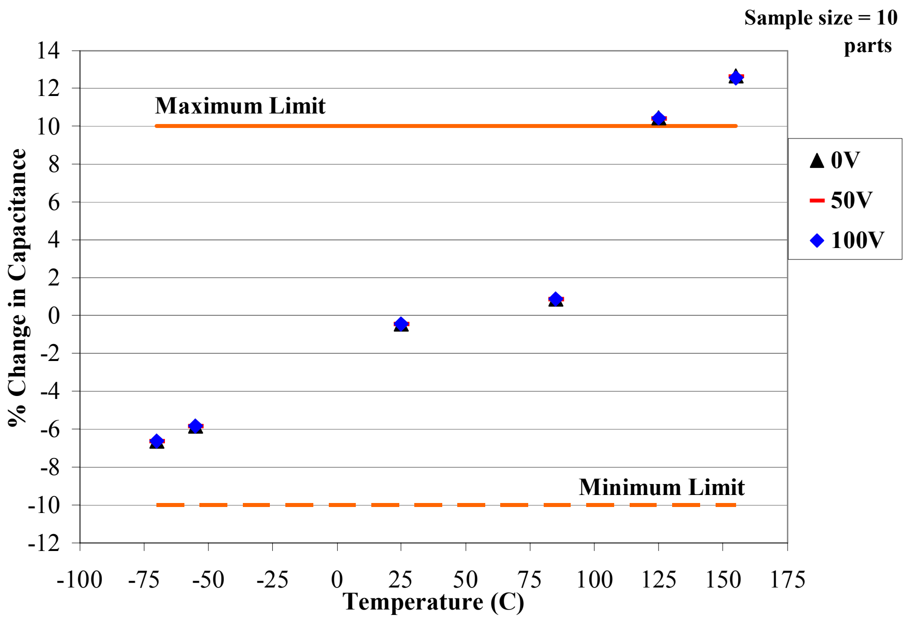

Figure 9: Temperature Dependency of PET Capacitor (Sample size = 10 parts)

Table 16: 6σ Spread for Capacitance of 106K100CS4G (Sample size = 10 parts)

Test temperature (°C)	Mean + 3σ (uF)	Mean - 3σ (uF)
-70	9.97	8.71
-55	10.23	8.61
25	10.62	9.30
85	10.78	9.40
125	11.46	10.62
155	11.71	10.81

Figure 10 shows the effect of temperature on the dissipation factor at 100V (100% rated voltage) and 1 KHz (datasheet specified test frequency). The dissipation factor value is outside the maximum specified limit at 125ºC for all voltages. The maximum observed value of dissipation factor is 1.4%, which was measured at

125°C. There is about a 40% decreases in the dissipation factor from 125ºC to 155ºC. This decrease in dissipation factor is associated with the molecular relaxation of the PET dielectric over the temperature range of 125°C to 155°C. The molecular relaxation of the PET dielectric is caused by the change in change in dielectric relaxation rate of PET dielectric from 125°C to 155°C [90].

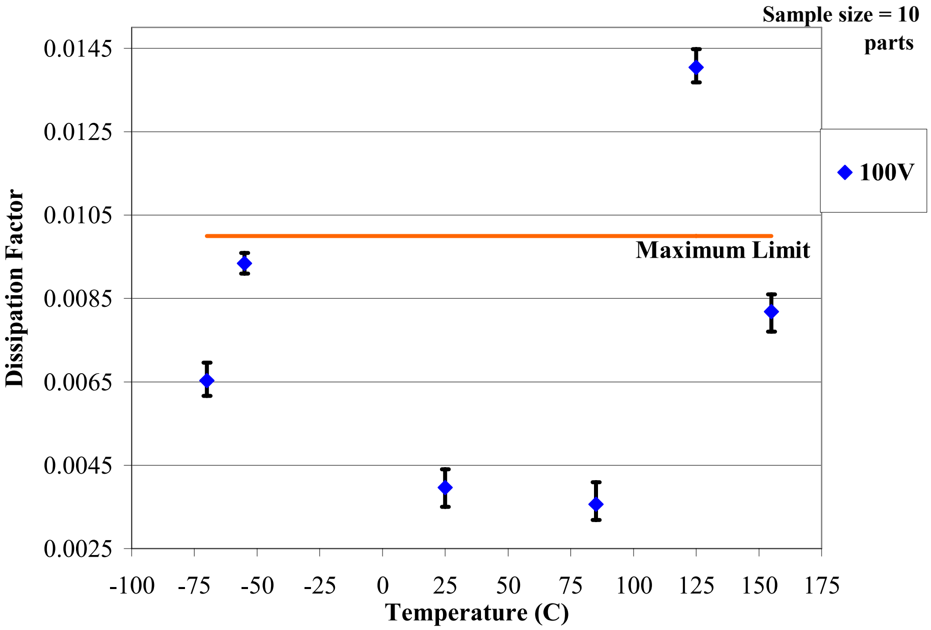

Figure 10: Effect of Temperature on Dissipation Factor of PET Capacitor (Sample size = 10 parts)

5.4.2 Effect of Frequency on Electrical Characteristics of PET Capacitor

Figure 11 shows the effect of frequency at 100V (100% rated voltage) and three frequencies (0.1 KHz, 1 KHz, and 10 KHz). The capacitance decreases slightly with increasing frequency. At 0.1 KHz, the capacitance is outside the manufacturer's specified maximum limit value. At 1 KHz, the capacitance is slightly outside the manufacturer's specified maximum limit value. The capacitance is within the manufacturer's specified maximum limit value at 10 KHz. At 155ºC, the capacitance values are outside the manufacturer's specified maximum limit value for all the three frequencies.

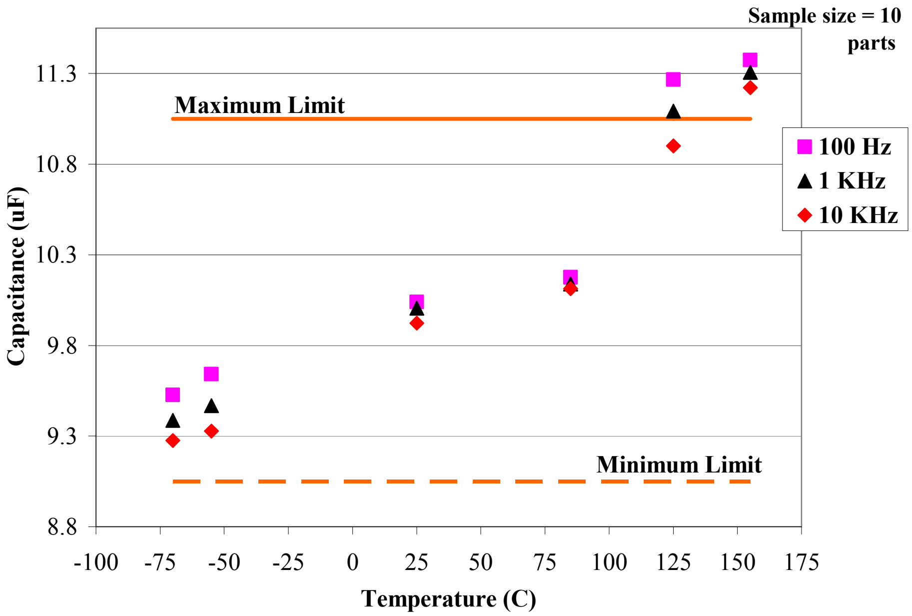

Figure 11: Effect of Frequency on Capacitance of PET Capacitor (Sample size = 10 parts)

Figure 12 shows the percentage deviation of capacitance from the nominal value (10 uF) over the frequency range of 0.1 to 10 KHz. It shows the frequency dependency at 100V (100% rated voltage) and three frequencies (0.1 KHz, 1 KHz, and 10 KHz). The capacitance decreases with increasing frequency. The capacitance values are outside the manufacturer's specified maximum limit at 125ºC for 0.1 and 1 KHz. The capacitance is within the manufacturer's specified maximum limit at 125ºC for 10 KHz. The capacitance value is outside the manufacturer's specified maximum limit at 155ºC for all the three frequencies.

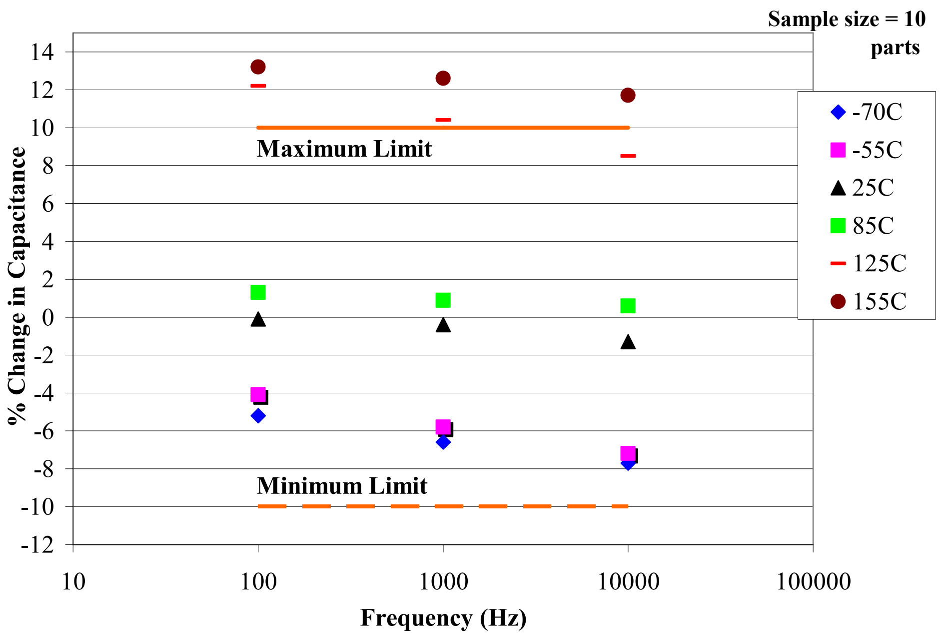

Figure 12: Frequency Dependency of PET Capacitor (Sample size = 10 parts)

Figure 13 shows the effect of frequency at 100V (100% rated voltage) and three frequencies (0.1 KHz, 1 KHz, and 10 KHz). The dissipation factor is outside the manufacturer's specified limit (given at 1 KHz) at 125ºC. At 10 KHz, the dissipation factor monotonically increases with the temperature over the temperature range of 25ºC to 155ºC.

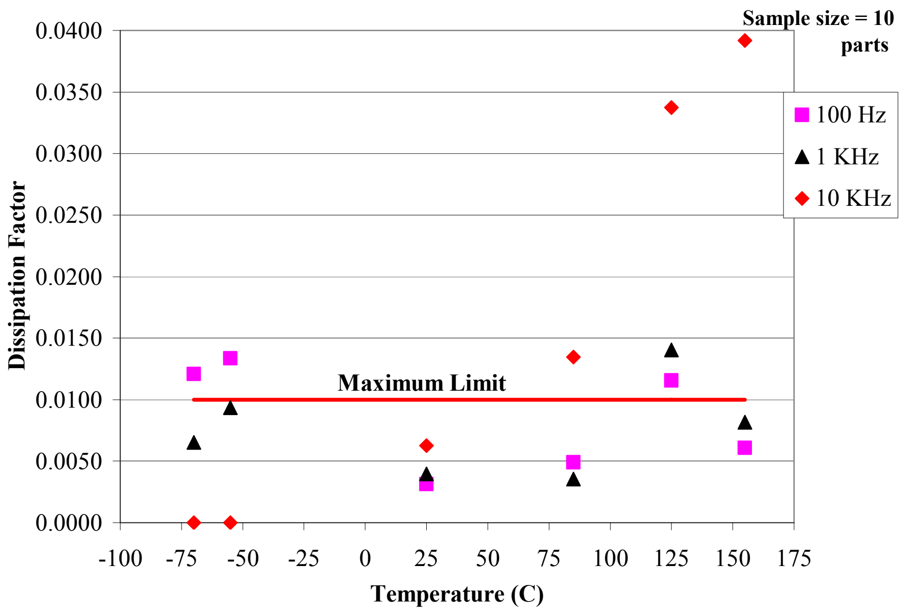

Figure 13: Effect of Frequency on Dissipation Factor of PET Capacitor (Sample size = 10 parts)

5.4.3 Effect of Voltage on Electrical Characteristics of PET Capacitor

The effect of voltage was measured by testing the capacitors at datasheet specified test frequency (1 KHz) and different DC bias voltages. Figure 14 shows the effect of voltage at 1 KHz and three DC bias voltage conditions (0V, 50V, and 100V). The capacitance values do not significantly change with different DC bias voltages and the trend is same for all temperatures.

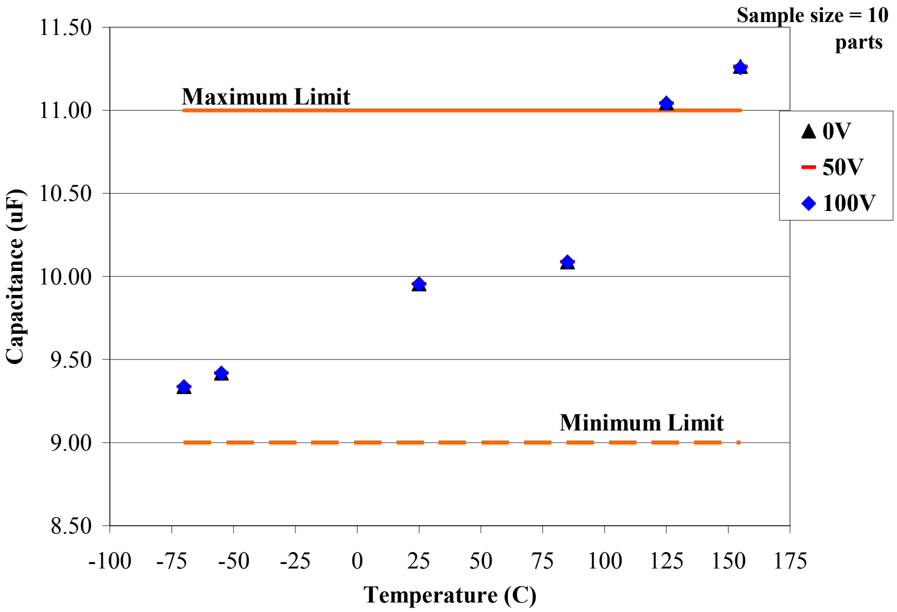

Figure 14: Effect of Voltage on Capacitance of PET Capacitor (Sample size = 10 parts)

Figure 15 shows the percentage deviation of capacitance from the nominal value (10 uF) over the voltage range of 0 to 100V. There is no significant deviation of capacitance from the nominal value over the voltage range of 0V to 100V.

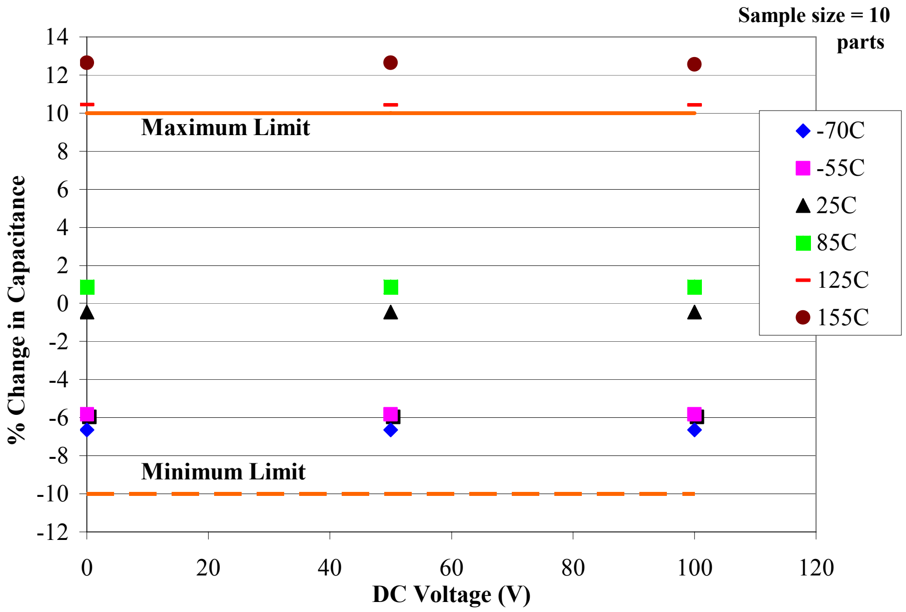

Figure 15: Voltage Dependency of PET Capacitor (Sample size = 10 parts)

Figure 16 shows the effect of voltage at 1 KHz (datasheet specified test frequency) and three DC bias voltage conditions (0V, 50V, and 100V). The dissipation factor does not change significantly with DC bias voltage.

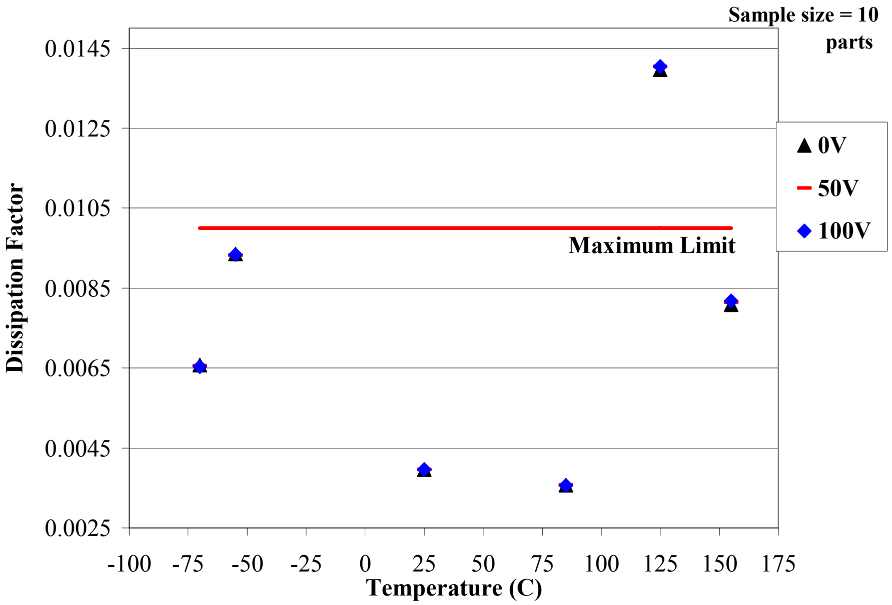

Figure 16: Effect of Voltage on Dissipation Factor of PET Capacitor (Sample size = 10 parts)

5.5 A Statistical Model for PET Capacitor

A statistical model has been developed based on the experimental results. This model relates capacitance with operating temperature and DC bias voltage over 0.1 to 10 KHz. The experimental results were used to develop the model using goodness of fit based on the linear regression correlation coefficient. Equation 1 shows the model for PET capacitor over 0.1 to 10 KHz.

$$C = C_0 + a \times V + b \times T \quad \text{- Equation (1)}$$

where C_0 is the nominal capacitance, V is the DC bias voltage in volts, and T is the operating temperature in ºC. In this study, the values of the constants are a = -5.58e-6 and b = 8.19e-3. Figure 17 compares the statistical model with the experimental result. The model is selected based on goodness of fit value of linear regression correlation coefficient and number of constants required. The value of linear regression correlation coefficient is 0.88 with 95% confidence limit. Constant "a" describes the effect of DC voltage on the capacitance. Constant "b" describes the effect of temperature on the capacitance.

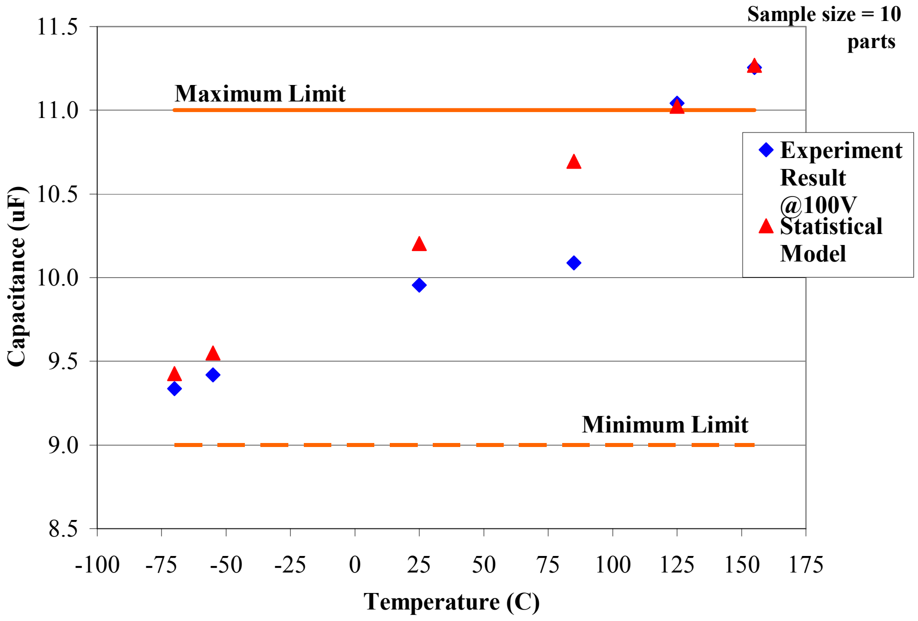

Figure 17: Comparison of Statistical Model with Experimental Result (Sample size = 10 parts)

The voltage coefficient does not affect capacitance significantly, which is also seen in experiment. The PET capacitor is stable with the DC voltage. The temperature coefficient has strong effect on the capacitance. The capacitance increases with the temperature over the range of -70ºC to 155ºC. The model incorporates the positive capacitance drift behavior of PET film with temperature. The voltage coefficient does not affect capacitance significantly, which is also seen in experiment.

The capacitance value of a capacitor is a function of the dielectric constant. The variation in capacitance value is primarily due to change in dielectric constant accordingly [39]. As the dielectric constant increases or decreases, the capacitance will increase or decrease, respectively [19]. The change in dielectric constant of PET film with temperature (See Figure 7) follows the similar trend as obtained from the statistical model for change in capacitance.

5.6 Conclusions

PET capacitors were investigated for use in applications which exhibits both low and high temperatures. The PET film capacitors were electrically characterized over the temperature range of -70ºC to 155ºC with varying voltage and frequency. Based on the experimental results, it is concluded that there is significant degradation performance of PET capacitor at high temperatures (~ 125ºC). PET film capacitor can be operated over the temperature range of -70ºC to 85ºC and the frequency range of 0.1 to 10 KHz. This PET capacitor is uprateable at low temperature end and has been uprated from ROC rating of -55 to 85°C to -70 to 85°C. This capacitor is may be uprateable at 115ºC. The experimental results validate the methodology that there is low chance of success in uprating of uprateability risk level three part. A statistical model based on experimental results has been developed for PET capacitor using goodness of fit. The model relates the capacitance with operating temperature, DC bias voltage, and frequency over 0.1 to 10 KHz.

Chapter 6: Uprateability Risk Assessment Case Study – III

The case study was conducted to assess one polymer film capacitor for uprateability which constitutes the Modular Avionic Control (MAC) system. The system manufacturer provided the maximum and minimum system ambient temperatures (-55°C to 115°C).

6.1 Polyphenylene Sulfide (PPS) Film Capacitor

Film capacitors use dielectrics that are polymer-based compounds, including polypropylene, polycarbonate and polyester. Polycarbonate film capacitors have been used for years in military, automotive, and industrial environments because of their capacitance stability at high temperatures (~ 125°C) [45]. However, in 2000, Wilhelm Westerman (WIMA) of Germany, the major manufacturer of polycarbonate (PC) film capacitors, announced that it was exiting the business because of low profitability. In reaction to WIMA's announcement, the largest single supplier of capacitor-grade polycarbonate raw material (tradename-Makrofol KG), Bayer AG, suspended productions of PC as a dielectric for capacitors [41].

An alternative to PC is Polyphenylene Sulfide (PPS). PPS and PC have about the same dielectric constant, so the size of a PPS replacement capacitor is approximately the same. The breakdown strength of PPS is 400V per micron thickness which is slightly higher than that of PC's 300V. This is important when considering replacement designs. For example, if the original PC design was based on 10µm thick film, it could be replaced with a 9µm thick PPS film. This actually decreases the overall voltage stress on the dielectric by 3% as well as gaining a modest reduction in the final capacitor's size [45]. However, the PPS dielectric films are not always available in the same thickness as those of PC.

PPS emerged as a suitable dielectric material for electronic applications due to several reasons. It is a stable crystalline polymer [45], with a melting point of 285°C [37]. Furthermore, it does not exhibit prominent deterioration when exposed to temperature close to the melting point for short period of time. The PPS film has excellent thermal resistance which allows encapsulation-free capacitors to endure reflow soldering. Moreover, the film combines minimal moisture absorption, stability to humidity variations, and nonflammability, can be manufactured in the ultra-thin form needed for compact capacitor design [44]. The dielectric absorption of PPS film is 0.05% as compared to 0.2% of PC at 25°C [50] [51]. The PPS capacitor under consideration is of metallized film type. Section 5.2 discusses the construction (See Figure 6) and advantages of metallized film type capacitors over the non-metallized. Table 17 shows the properties of PPS film and compares them with PC film.

Table 17: Properties of PPS and PC Films [8], [15]

Property	PPS	PC
Dielectric Constant	3.1	3.0
Dielectric Loss (%)	0.06	0.1 ~ 0.3
Breakdown Voltage (V/μ)	400	350
Melting Point (°C)	285	220 ~ 240
Water Absorption	0.05 ~ 0.1	0.2 ~ 0.3

PPS has a negative temperature coefficient of capacitance until about 75°C where the capacitance is between ±2% of its original capacitance. Beyond 100°C, the capacitance begins to rapidly increase at a rate of 1200 ppm/°C, primarily due to the variation of the dielectric constant of PPS film. The change in dielectric constant of PPS film "Torelina" with temperature is shown in Figure 18; the property change trends follow the reported changes in capacitance over temperature.

The dissipation factor measures the basic inefficiency of the capacitor. It varies as a function of both temperature and frequency [92]. The dissipation factor of PPS is within 0.1% up to 100°C. Beyond 100°C, it increases to about 0.5% at 125°C. The dissipation factor does not change significantly at operating frequencies below 100 KHz. The dissipation factor starts increasing beyond ~100 KHz for all temperatures [33], [36].

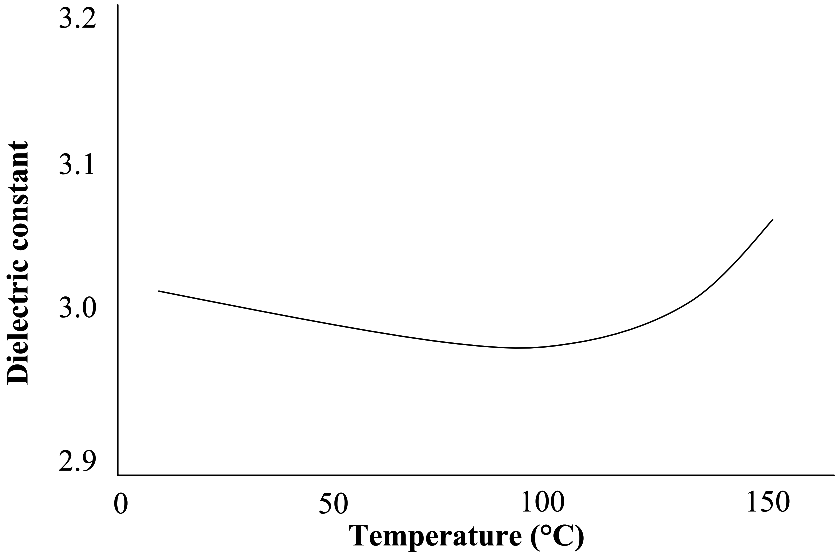

Figure 18: Change in Dielectric Constant of PPS film "Torelina" with Temperature [14]

6.2 Uprateability Risk Assessment of Polyphenylene Sulfide (PPS) Film Capacitor

The PPS film capacitor constitutes the Modular Avionic Control (MAC) system. The system manufacturer provided the maximum and minimum system ambient temperatures (-55°C to 115°C).

6.2.1 Collection of Necessary Information: Step – 1

The polymer film capacitor selected for the uprateability risk assessment is of metallized film type with Polyphenylene Sulfide (PPS) as dielectric material. The PPS capacitor selected for this investigation had a nominal capacitance of 100 nF at 1 KHz, temperature rating of -55ºC to 125ºC, voltage rating of 16V, maximum dissipation factor value of 0.6% at 1 KHz, and a capacitance tolerance of ± 2%. There is no AMR temperature rating provided for the part. The melting point (285°C) was obtained as material dependent thermal parameter. The manufacture conducts the high temperature life test at 125°C (T_{HTL}) for 1000 hours.

6.2.2 Analysis of Information: Step – 2

The melting point (285°C) of PPS dielectric is considered as the AMR estimate in the uprateability risk assessment as the manufacturer does not provide the AMR temperature rating in the datasheet.

6.2.3 Uprateability Risk Level Assignment: Step – 3

The part and manufacturer assessment were conducted based on the developed guidelines [30]. The part assessment categories include average outgoing quality (AOQ), process capability index (C_{pk}), integrity monitor test results, and assembly guidelines. Cornell Dubilier’s part, FCP1210C104G-G3, passed the part assessment. Table 18 shows the part assessment results [30].

Table 18: Part Assessment of FCP1210C104G-G3 [88], [93]

Part Assessment Categories and Results			
Average Outgoing Quality (AOQ) (ppm)	C_{pk}	Integrity monitor test results	Assembly guidelines
0.1 – Passed	> 1 – Passed	Passed	Passed

The manufacturer assessment categories include process control, handling, storage and shipping control, corrective and preventive action, product traceability, and change notification. Cornell Dubilier passed the manufacturer assessment. Table 19 shows the manufacturer assessment results [30].

Table 19: Manufacturer Assessment of Cornell Dubilier [30]

Manufacturing Assessment Criteria and Results				
Process control	Handling, storage, and shipping control	Corrective and preventive action	Product traceability	Change notification
Passed	Passed	Passed	Passed	Passed

Cornell Dubilier part FCP1210C104G-G3, a PPS film capacitor, is assigned risk level 1 based on the methodology since the system ambient temperature (-55 to 115°C) is within the part's ROC temperature rating (-55 to 125°C). It signifies that the PPS capacitor does not need to be uprated as per the methodology. However, this PPS capacitor is electrically tested to validate the uprateability risk assessment methodology that a risk level 1 part does not need to be uprated.

6.3 Uprating of Risk Level 1 PPS Capacitor

Cornell Dubilier's film capacitor FCP1210C104G-G3 was assigned uprateability risk level one. Fifteen PPS capacitors were tested over the temperature range of

-70ºC to 155ºC with varying DC bias voltage (0, 8, and 16V) and frequency (0.1, 1, 10, and 100 KHz). The capacitance and dissipation factor were measured.

The capacitors were tested using an external voltage bias fixture, coupled to an LCR meter and voltage source. The LCR meter was compensated for open and short corrections using the same length of wire used for each capacitor. A control sample from each group was tested at zero DC bias with different frequencies to formulate the experimental plan. The capacitance and dissipation factor were measured at different temperatures by changing the DC bias voltage and frequency. Temperature was controlled by Temptronic Thermal Control equipment.

The capacitors were tested initially at 25ºC. Subsequently, the capacitors were tested at -55ºC and -70ºC respectively. Later on, the capacitors were brought back to 25ºC. Subsequently, the capacitors were tested at 75ºC, 125ºC, and 155ºC respectively.

After the experiment, the average values of capacitance and dissipation factor were determined. The results were compared to the capacitance and dissipation factor values provided in the datasheet. The maximum and minimum limit values were calculated using the tolerance value (±2%) provided in the datasheet of the PPS capacitor.

6.3.1 Effect of Temperature on Electrical Characteristics of PPS Capacitor

Figure 19 shows the effect of temperature on the capacitance at 16V (100% rated voltage) and 1 KHz (datasheet test frequency)[15]. The capacitance decreases with the increasing temperature up to ~100ºC and after that it starts increasing.

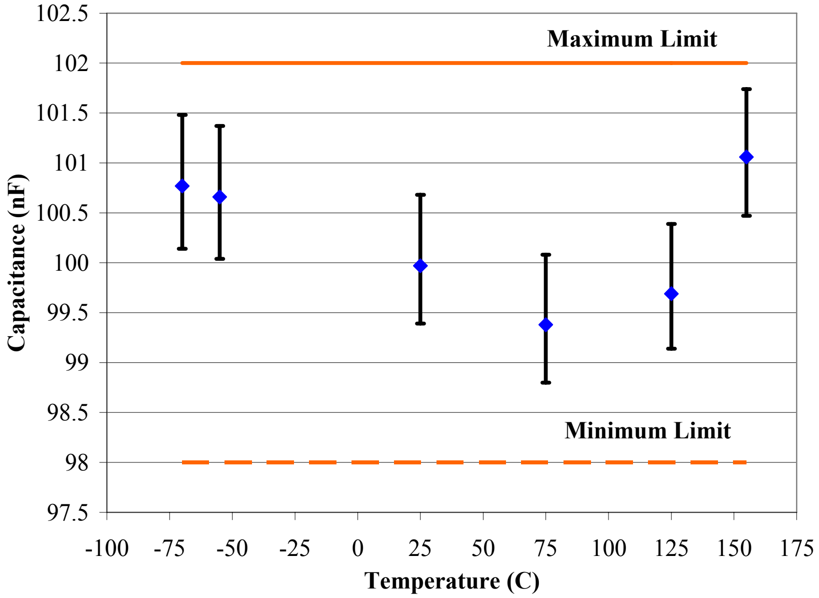

Figure 19: Effect of Temperature on Capacitance of PPS Capacitor (Sample size = 15 parts)

Figure 20 shows the percentage deviation of capacitance from the nominal value (100 nF) over the temperature range of -70ºC to 155ºC at 1 KHz (datasheet specified test frequency) and three DC bias voltage conditions (0V, 8V, and 16V). The temperature drift varies between -0.6% to +1% between -55°C to 125°C. At room temperature, there is almost zero deviation in the capacitance values from the nominal value of 100 nF. The maximum deviation of 1% from the nominal value is observed

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[15] The manufactures generally provide the electrical parameters values for a capacitor at constant frequency and temperature. For PPS capacitor under investigation, the manufacturers provide electrical parameters values at 1 KHz without any mention of test temperature.

at 155ºC. Table 20 shows the 6σ spread for capacitance of the PPS capacitor at 16V and 1 KHz.

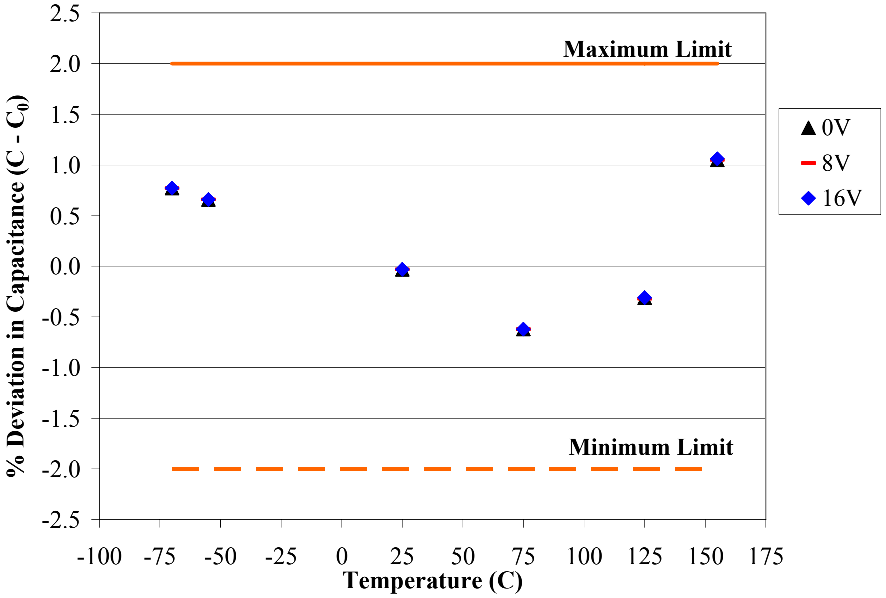

Figure 20: Temperature Dependency of PPS Capacitor (Sample size = 15 parts)

Table 20: 6σ Spread for Capacitance of FCP1210C104G-G3
(Sample size = 15 parts)

Test temperature (°C)	Mean + 3σ (nF)	Mean - 3σ (nF)
-70	101.97	99.57
-55	101.86	99.46
25	101.14	98.80
85	100.52	98.24
125	100.83	98.55
155	102.26	99.86

Figure 21 shows the effect of temperature on the dissipation factor at 16V (100% rated voltage) and 1 KHz (datasheet specified test frequency). The maximum limit denotes the value provided in the datasheet. The maximum observed value of dissipation factor is 0.32%.

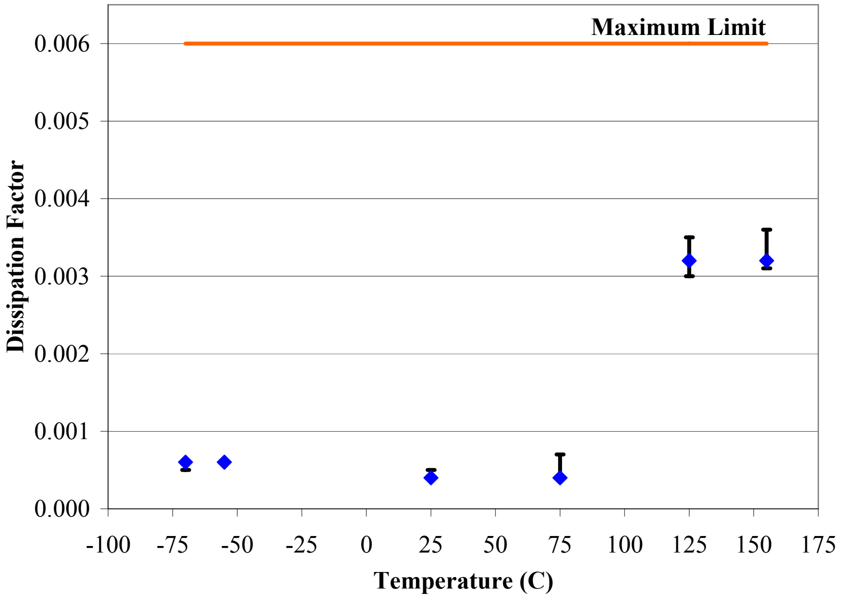

Figure 21: Effect of Temperature on Dissipation Factor of PPS Capacitor (Sample size = 15 parts)

6.3.2 Effect of Frequency on Electrical Characteristics of PPS Capacitor

Figure 22 shows the effect of frequency at 16V (100% rated voltage) and four frequencies (0.1, 1, 10, and 100 KHz). The frequency does not have significant influence on the capacitance in the range of 0.1 to 100 KHz over the temperature range of -70ºC to 75ºC. Above 75ºC, the capacitance decreases with increasing frequency.

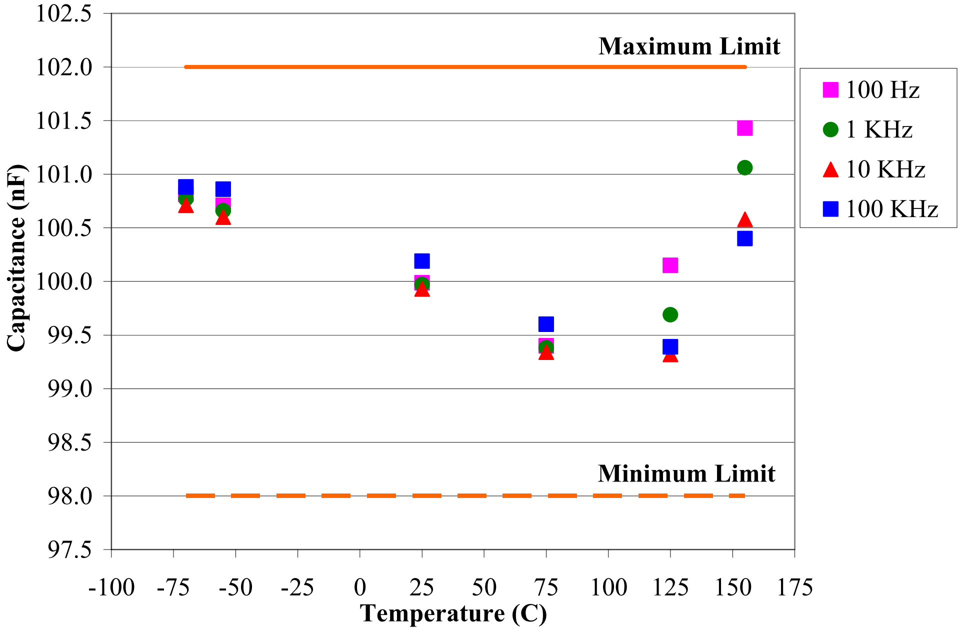

Figure 22: Effect of Frequency on Capacitance of PPS Capacitor (Sample size = 15 parts)

Figure 23 shows the percentage deviation of capacitance from the nominal value (100 nF) over the frequency range of 0.1 KHz to 100 KHz. It shows the frequency dependency at 16V (100% rated voltage) and four frequencies (0.1, 1, 10, and 100 KHz). At 155ºC, the capacitance decreases monotonically with the increasing frequency.

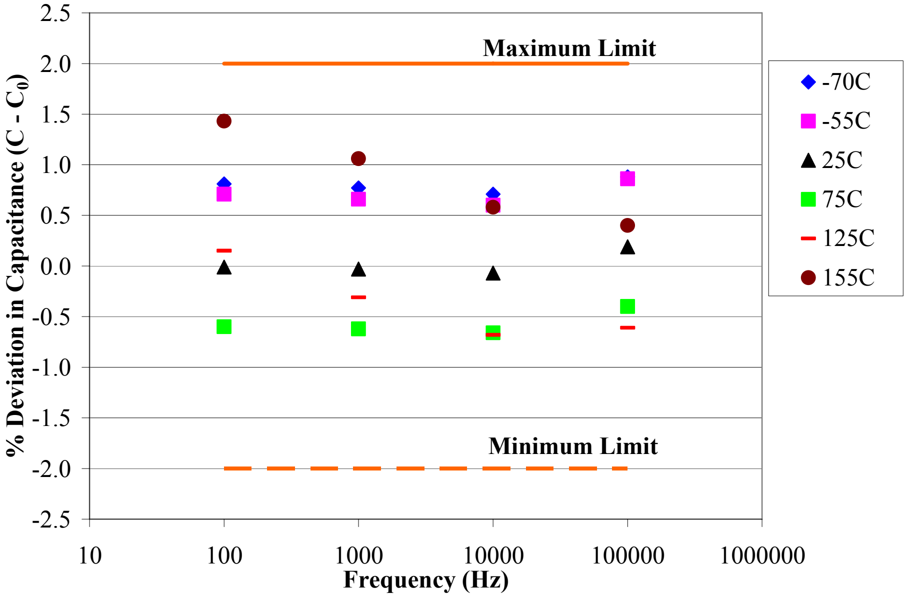

Figure 23: Frequency Dependency of PPS Capacitor (Sample size = 15 parts)

Figure 24 shows the effect of frequency at 16V (100% rated voltage). Four frequencies (0.1, 1, 10, and 100 KHz) were used in the testing. The dissipation factor value is outside the manufacturer's specified limit (0.6% @ 1 KHz) at test conditions 100 KHz and 155ºC. The dissipation factor increases monotonically with temperature at 100 KHz. The dissipation factor does not change monotonically with temperature below ~100 KHz.

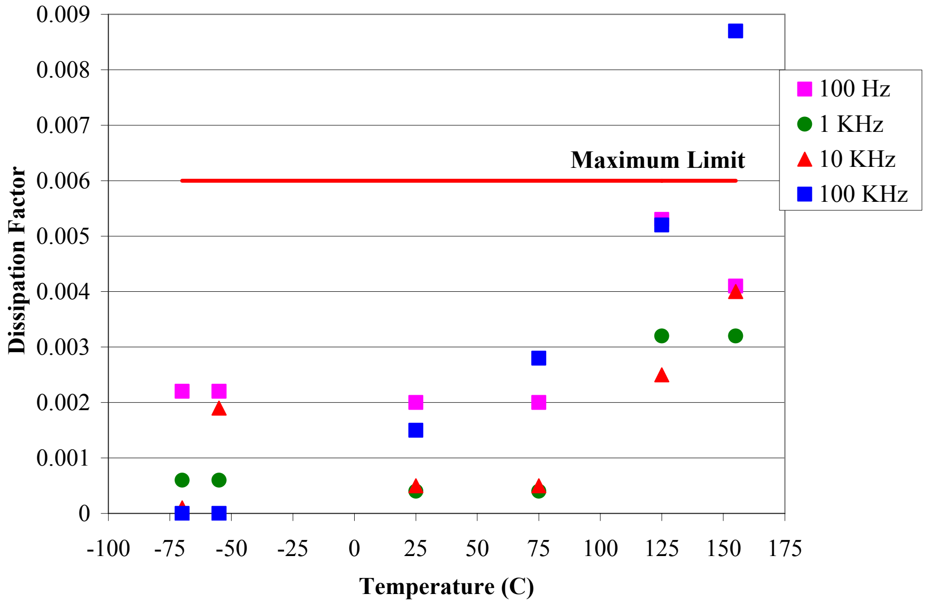

Figure 24: Effect of Frequency on Dissipation Factor of PPS Capacitor (Sample size = 15 parts)

6.4 Effect of Voltage on Electrical Characteristics of PPS Capacitor

The effect of voltage was measured by testing the capacitors at datasheet specified test frequency (1 KHz) and different DC bias voltages. Figure 25 shows the effect of voltage at 1 KHz and three DC bias voltage conditions (0V, 8V, and 16V). The capacitance values do not change with different DC bias voltages and the trend is same for all temperatures.

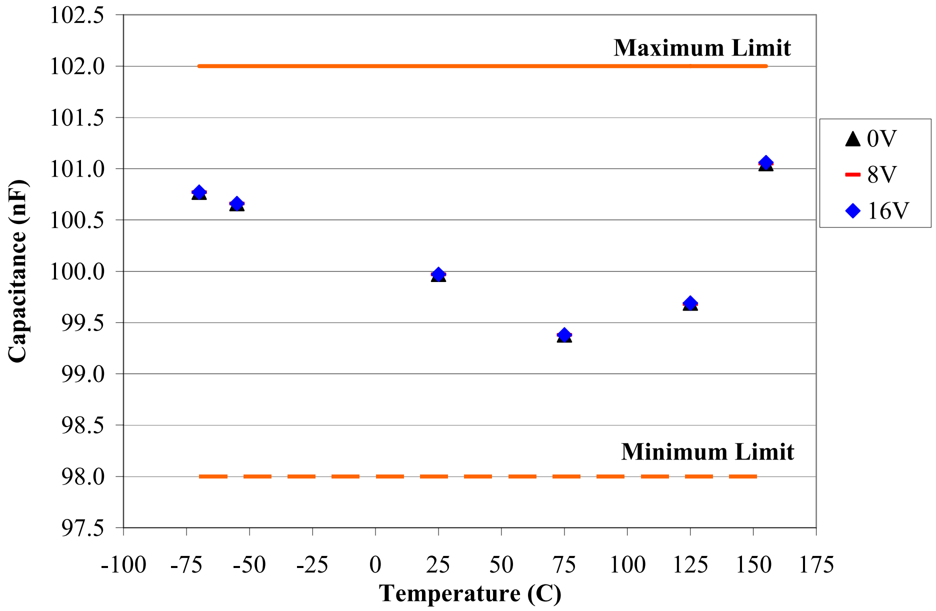

Figure 25: Effect of Voltage on Capacitance of PPS Capacitor (Sample size = 15 parts)

Figure 26 shows the percentage deviation of capacitance from the nominal value (100 nF) over the voltage range of 0V to 16V. There is no significant deviation of capacitance from the nominal value over the voltage range of 0V to 16V.

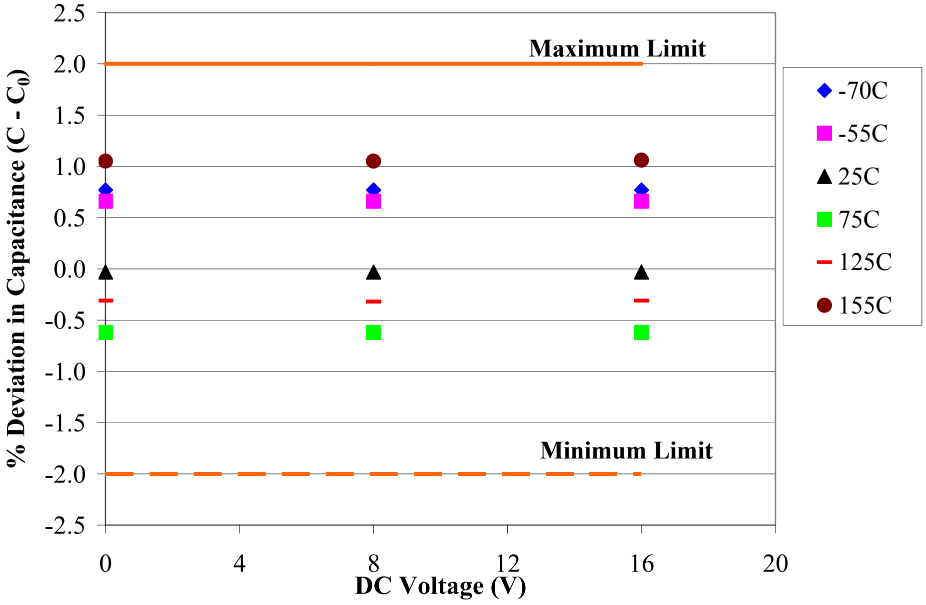

Figure 26: Voltage Dependency of PPS Capacitor (Sample size = 15 parts)

Figure 27 shows the effect of voltage at 1 KHz (datasheet specified test frequency) and three DC bias voltage conditions (0V, 8V, and 16V). There is no significant change in the dissipation factor at different voltages.

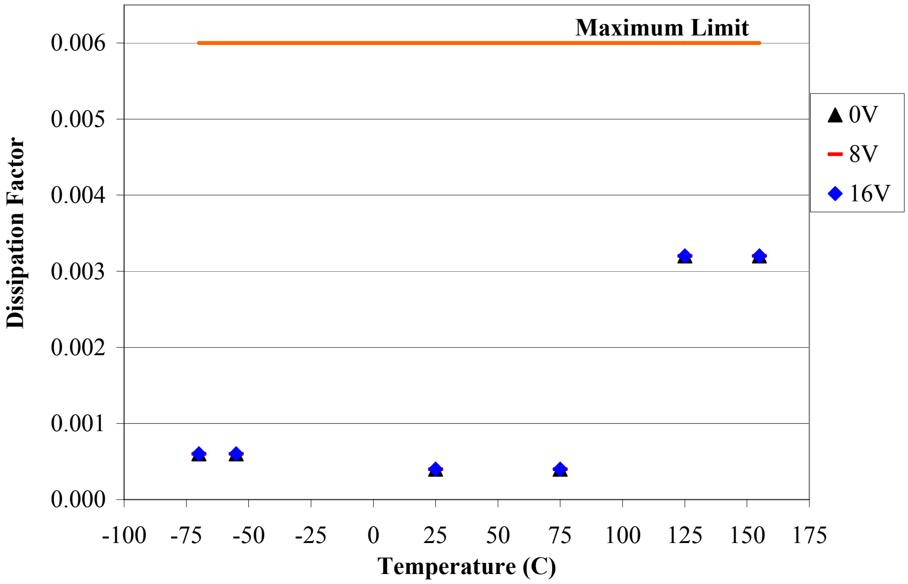

Figure 27: Effect of Voltage on Dissipation Factor of PPS Capacitor (Sample size = 15 parts)

6.5 A Statistical Model for PPS Capacitor

A statistical model has been developed based on the experimental results. This model relates capacitance with operating temperature, DC bias voltage, and frequency over 0.1 to 100 KHz. The experimental results were used to develop the model using goodness of fit based on the linear regression correlation coefficient. Equation 1 shows the model for PPS capacitor over 0.1 to 100 KHz.

$$C = C_0 + a \times V + b \times T + c \times T^3 \text{ - Equation (1)}$$

where C_0 is the nominal capacitance, V is the DC bias voltage in volts, and T is the operating temperature in ºC. In this study, the values of the constants are a = 1e-4, b = -1.39e-2, and c = 9.13e-7. Figure 28 compares the statistical model with the experimental result. The model is selected based on goodness fit value of linear regression correlation coefficient and number of constants required. The value of linear regression correlation coefficient is 0.98 with 95% confidence limit. Constant "a" describes the effect of DC voltage on the capacitance. Two constants "b" and "c" describe the effect of temperature on the capacitance.

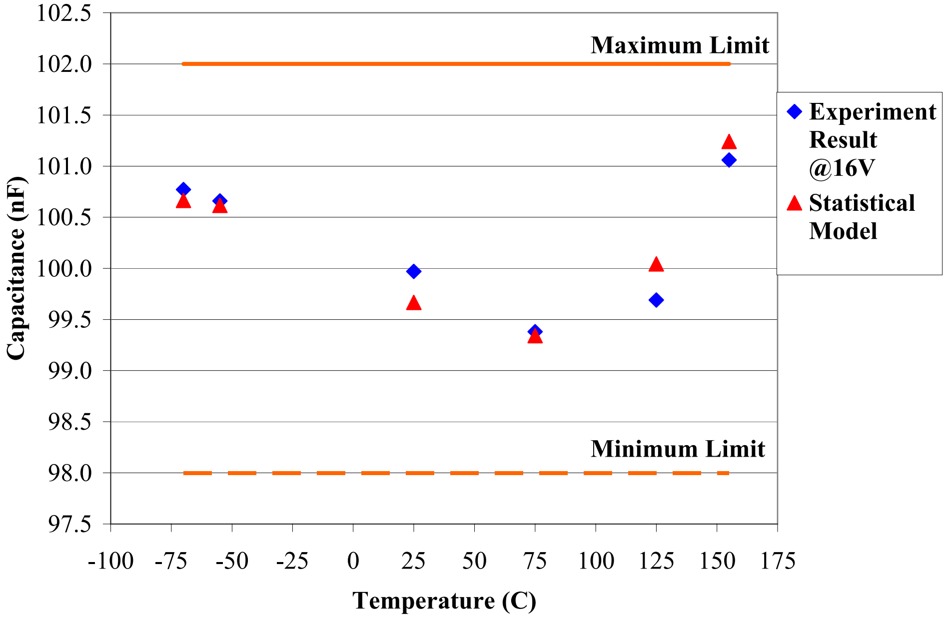

Figure 28: Comparison of Statistical Model with Experimental Result (Sample size = 15 parts)

The voltage coefficient does not affect capacitance significantly, which is also seen in experiment. The PPS capacitor is stable with the DC voltage. The temperature coefficients have strong effect on the capacitance. The capacitance decreases with the temperature over the range of -70ºC to 75ºC. After 75ºC, the capacitance increases with the temperature. The model incorporates the positive capacitance drift behavior of PPS film at high temperature.

The capacitance value of a capacitor is a function of the dielectric constant. The variation in capacitance value is primarily due to change in dielectric constant accordingly [39]. As the dielectric constant increases or decreases, the capacitance will increase or decrease, respectively [91]. The change in dielectric constant of PPS film with temperature (See Figure 18) follows the similar trend as obtained from the statistical model for change in capacitance.

6.6 Conclusions

The PPS film capacitors were electrically characterized over the temperature range of -70ºC to 155ºC with varying voltage and frequency to demonstrate its behavior over a wide temperature range, needed in many electronic applications. Based on the experimental results, it is concluded that the PPS film capacitor conforms to the manufacturer's specified capacitance and dissipation factor values over the temperature range of -70ºC to 155ºC. The PPS capacitor is uprateable over the temperature range of -70ºC to 155ºC over the frequency range of 0.1 to 100 KHz. The PPS capacitor has been uprated using parameter re-characterization method of uprating. The experimental results validate the methodology that the uprateability risk level one part does not need to be uprated. The experimental results provide high degree of confidence for use of PPS capacitors in applications which require that the parts are used at low and high temperature. A statistical model based on experimental results has been developed for PPS capacitor using goodness of fit. The model co-relates the capacitance with operating temperature and DC bias voltage over 0.1 to 100 KHz.

Contributions

The “enhanced plastic” parts have been analyzed first time to assess them as alternative to uprating. The enhanced plastic parts have been assessed compared to the equivalent commercial off-the-shelf (COTS) parts based on availability, recommended operating temperature ratings, electrical parameters, package types, qualification methods, and price.

The methodology for uprateability risk assessment of electronic parts has been developed. The methodology has been demonstrated and validated for an operational amplifier and two polymer film capacitors. Complete analysis beginning from manufacturer and part assessment through electrical test results analysis has been performed to show the uprateability risk assessment process. Statistical models have been developed for capacitors correlating capacitance with operating temperature and DC bias voltage over a range of frequencies.

APPENDIX: A

Texas Instruments (TI) Enhanced Plastic Parts

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
Digital Signal Processors	1	SM320VC33GNMM150EP[16]	(-55, 125)	104.25	10	NU
		SM320VC33GNMM150	(-55, 125)	94.77		
	2	SM320VC33PGEA120EP	(-40, 100)	24.53	100	NU
		TMS320VC33PGEA120	(-40, 100)	12.84		
	3	SM320C32PCMM50EP	(-55, 125)	34.92	100	U
		TMS320C32PCM50	(-40, 125)	18.85		
	4	SM320C32PCMM60EP	(-55, 125)	38.41	100	U
		TMS320C32PCM60	(-40, 125)	19.19		
	5	SM320C50PQM66EP	(-55, 125)	68.82	121	U
		TMS320C50PQ57	(-40, 85)	33.63		
	6	SM320LC31PQM40EP	(-55, 125)	56.27	100	U
		TMS320LC31PQ40	(0, 85)	30.38		
	7	SM320C6202GJLA20EP	(-40, 105)	225.74	100	U
		TMS320C6202GJLA200	(0, 90)	112.83		
	8	SM320VC5409GGU10EP	(-40, 100)	19.48	100	NU
		TMS320VC5409GGU100	(-40, 100)	9.74		
	9	SM320VC5416PGE16EP	(-40, 100)	51.15	91	NU
		TMS320VC5416PGE160	(-40, 100)	26.84		
	10	SM320VC5416GGU16EP	(-40, 100)	51.15	91	NU
		TMS320VC5416GGU160	(-40, 100)	26.84		
	11	SM320VC5421PGE20EP	(-40, 85)	118.19	100	U
		TMS320VC5421PGE200	(0, 85)	59.07		
	12	SM320LF2407APGEMEP	(-55, 125)	20.66	100	U
		TMS320LF2407APGES	(-40, 125)	10.33		
	13	SM320C6701GJCA12EP	(-40, 125)	180.76	100	U
		TMS320C6701GJCA120	(-40, 105)	90.35		
	14	SM32C6713BGDPA20EP	(-40, 105)	69.94	100	NU
		TMS320C6713GDPA200	(-40, 105)	28.99		
	15	SM320C6201GJCA20EP	(-40, 105)	165.47	100	U
		TMS320C6201GJC200	(0, 90)	82.70		
	16	SMC6701MECHGJC16EP	(0, 90)	226.99	82	NU
		TMSC6701GJC16719V	(0, 90)	124.66		
	17	SM32VC5510AGGWA2EP	(-40, 85)	69.31	169	NU
		TMS320VC5510AGGWA2	(-40, 85)	25.76		
	18	SM320F2812GHHMEP	(-55, 125)	36.22	83	U
		TMS320F2812GHHQ	(-40, 125)	19.80		
	19	SM320F2812PGFMEP	(-55, 125)	36.22	83	U
		TMS320F2812PGFQ	(-40, 125)	19.80		
	20	SM32C6711DGDPA16EP	(-40, 105)	48.82	140	U
		TMS32C6711DGDPA167	(0, 90)	20.34		
	21	SM32C6712DGDPA16EP	(-40, 105)	30.52	111	U
		TMS320C6712DGDP150	(0, 90)	14.49		
	22	SM32C6414DGLZ50AEP	(-40, 105)	174.92	77	NU
		TMS32C6414DGLZA5E0	(-40, 105)	98.84		
	23	SM32C6415DGLZ50AEP	(-40, 105)	208.08	NA	NU
		TMS32C6415DGLZA5E0	(-40, 105)	NA		

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[16] This DSP EP part SM320VC33GNMM150EP is not a plastic packaged part but a ceramic one. Although the DSP part number has the suffix "EP," the package type is ceramic ball grid array (CBGA), the same as its equivalent COTS part SM320VC33GNMM150 [35].

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
	24	SM32C6416DGLZ50AEP	(-40, 105)	228.88	100	NU
		TMS32C6416DGLZA5E0	(-40, 105)	114.44		
1394	1	TSB12LV01BIPZTEP	(-40, 85)	17.47	78	NU
		TSB12LV01BIPZT	(-40, 85)	9.80		
	2	TSB12LV26TPZEP	(-40, 110)	12.51	188	U
		TSB12LV26IPZT	(-40, 85)	4.35		
	3	TSB12LV32TPZEP	(-40, 110)	12.65	124	U
		TSB12LV32IPZ	(-40, 85)	5.65		
	4	TSB41AB3IPFPEP	(-40, 85)	8.69	163	NU
		TSB41AB3IPFP	(-40, 85)	3.30		
	5	TSB41BA3ATPFPEP	(-40, 110)	32.97	361	U
		TSB41BA3AIPFP	(-40, 85)	7.15		
	6	TSB43AA82AIPGEEP	(-40, 85)	22.76	150	NU
		TSB43AA82AIPGE	(-40, 85)	9.10		
	7	TSB43AB21AIPDTEP	(-40, 85)	12.51	163	NU
		TSB43AB21AIPDT	(-40, 85)	4.75		
	8	TSB43AB23IPDTEP	(-40, 85)	13.48	175	U
		TSB43AB23PDT	(0, 70)	4.90		
	9	TSB81BA3IPFPEP (p)	(-40, 85)	32.62	279	NU
		TSB81BA3IPFP	(-40, 85)	8.60		
	10	TSB82AA2IPGEEP	(-40, 85)	32.62	279	NU
		TSB82AA2IPGE	(-40, 85)	8.60		
Analog-to-Digital Converter	1	THS1206MDAREP	(-55, 125)	17.61	83	U
		THS1206QDAR	(-40, 125)	9.60		
	2	THS1401QPHPEP	(-40, 125)	20.48	100	NU
		THS1401QPHP	(-40, 125)	10.25		
	3	THS1403QPHPEP	(-40, 125)	25.39	100	NU
		THS1403QPHP	(-40, 125)	12.70		
	4	THS1408MPHPEP	(-55, 125)	18.09	6	U
		THS1408QPHP	(-40, 125)	17.05		
	5	TLC1543QDWREP	(-40, 125)	5.56	142	NU
		TLC1543QDWR	(-40, 125)	2.30		
	6	TLC2543QDWREP	(-40, 125)	9.85	107	U
		TLC2543IDWR	(-40, 85)	4.75		
	7	TLV1548QDBREP	(-40, 125)	4.36	78	U
		TLV1548IDBR	(-40, 85)	2.45		
Digital-to-Analog Converter	1	TLV5618AMDREP	(-55, 125)	11.79	136	U
		TLV5618AQDR	(-40, 125)	5.00		
	2	TLV5619QDWREP	(-40, 125)	7.91	143	NU
		TLV5619QDWR	(-40, 125)	3.25		
	3	TLV5638MDREP	(-55, 125)	10.20	155	U
		TLV5638IDR	(-40, 85)	4.00		
	4	TLV5638QDREP	(-40, 125)	9.34	103	NU
		TLV5638QDR	(-40, 125)	4.60		
Comparator	1	TLC3702MDREP	(-55, 125)	1.18	168	NU
		TLC3702MDR	(-55, 125)	0.44		
	2	TLV3701QDBVREP	(-40, 125)	1.79	198	U
		TLV3701CDBVR	(0, 70)	0.6		
	3	LM211QDREP	(-40, 125)	0.62	48	NU
		LM211QDR	(-40, 125)	0.42		
	4	LM239AQDREP	(-40, 125)	0.76	230	U
		LM239ADR	(-25, 125)	0.23		
Interface	1	PCI1520IGHKEP	(-40, 85)	15.42	221	NU
		PCI1520IGHK	(-40, 85)	4.80		
	2	PCI1520IPDVEP	(-40, 85)	15.42	221	NU

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
		PCI1520IPDV	(-40, 85)	4.80		
	3	SN65LBC176AMDREP	(-55, 125)	3.68	207	U
		SN65LBC176ADR	(-40, 85)	1.20		
	4	SN65LBC176AQDREP	(-40, 125)	3.51	181	NU
		SN65LBC176AQDR	(-40, 125)	1.25		
	5	SN65LVDS95DGGREP	(-40, 85)	10.33	162	NU
		SN65LVDS95DGGR	(-40, 85)	3.95		
	6	SN65HVD10QDREP	(-40, 125)	4.63	93	NU
		SN65HVD10QDR	(-40, 125)	2.40		
	7	SN65HVD12IDREP	(-40, 85)	4.38	150	NU
		SN65HVD12DR	(-40, 85)	1.75		
	8	TL16C752BTPTREP	(-40, 110)	13.00	319	U
		TL16C752BPTR	(-40, 85)	3.10		
DC/DC Controller	1	TPS5120QDBTREP	(-40, 125)	7.99	185	U
		TPS5120DBTR	(-20, 85)	2.80		
	2	TPS54680QPWPREP	(-40, 125)	9.25	137	U
		TPS54680PWPR	(-40, 85)	3.90		
Logarithmic Amplifier	1	TL441MNSREP	(-55, 125)	6.80	110	U
		TL441CNSR	(0, 70)	3.24		
Operational Amplifier	1	TLC2252QDREP	(-40, 125)	1.65	154	NU
		TLC2252QDR	(-40, 125)	0.65		
	2	TLC2252AQDREP	(-40, 125)	1.74	149	NU
		TLC2252AQDR	(-40, 125)	0.70		
	3	TLC2254QDREP	(-40, 125)	2.29	186	NU
		TLC2254QDR	(-40, 125)	0.80		
	4	TLC2254AQDREP	(-40, 125)	2.41	184	NU
		TLC2254AQDR	(-40, 125)	0.85		
	5	TLC2272AMDREP	(-55, 125)	1.74	118	U
		TLC2272AMDR	(-55, 125)	0.80		
	6	TLC2274MDREP	(-55, 125)	2.49	162	NU
		TLC2274MDR	(-55, 125)	0.95		
	7	TLC2274MPWREP	(-55, 125)	2.49	232	U
		TLC2274IPWR	(-40, 125)	0.75		
	8	TLC2274AMDREP	(-55, 125)	2.60	174	NU
		TLC2274AMDR	(-55, 125)	0.95		
	9	TLC2274AMPWREP	(-55, 125)	2.60	225	U
		TLC2274AIPWR	(-40, 125)	0.80		
	10	TLE2021QDREP	(-40, 125)	1.50	150	NU
		TLE2021MD	(-55, 125)	0.60		
	11	TLE2021AQDREP	(-40, 125)	1.50	173	U
		TLE2021ACDR	(0, 70)	0.55		
	12	TLE2022QDREP	(-40, 125)	2.00	150	U
		TLE2022IDR	(-40, 85)	0.80		
	13	TLE2022AQDREP	(-40, 125)	2.88	150	U
		TLE2022AIDR	(-40, 85)	1.15		
	14	TLE2024QDWREP	(-40, 125)	3.88	110	NU
		TLE2024MDW	(-55, 125)	1.85		
	15	TLE2024AQDWREP	(-40, 125)	4.50	173	U
		TLE2024AQDWREP	(0, 70)	1.65		
	16	TLV2252QDREP	(-40, 125)	2.60	271	NU
		TLV2252QDR	(-40, 125)	0.70		
	17	TLV2252AQDREP	(-40, 125)	2.73	290	NU
		TLV2252AQDR	(-40, 125)	0.70		
	18	TLV2254QDREP	(-40, 125)	3.60	227	NU
		TLV2254QDR	(-40, 125)	1.10		

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
	19	TLV2254AQDREP	(-40, 125)	3.60	227	NU
		TLV2254AQDR	(-40, 125)	1.10		
	20	TLV2462AQDREP	(-40, 125)	2.32	144	NU
		TLV2462AQDR	(-40, 125)	0.95		
	21	TLV2463AQDREP	(-40, 125)	2.49	149	NU
		TLV2463AQDR	(-40, 125)	1.00		
High Speed Amplifier	1	THS3201MDGNREP	(-55, 125)	4.40	175	U
		THS3201DGNR	(-40, 85)	1.60		
	2	THS4271MDGNREP	(-55, 125)	7.84	175	U
		THS4271DGNR	(-40, 85)	2.85		
	3	THS4503MDGNREP	(-55, 125)	11.28	175	U
		THS4503IDGNR	(-40, 85)	4.10		
PWM Controller	1	UC2875SDWREP	(-25, 110)	8.02	50	U
		UC2875DWP	(-25, 85)	5.35		
Supervisor	1	TPS3803-01MDCKREP	(-55, 125)	0.89	256	U
		TPS3803-01DCKR	(-40, 85)	0.25		
	2	TPS3803-01QDCKREP	(-40, 125)	0.61	110	NU
		TPS3803-01QDCKRQ1	(-40, 125)	0.29		
	3	TPS3803G15MDCKREP	(-55, 125)	0.89	256	U
		TPS3803G15DCKR	(-40, 85)	0.25		
	4	TPS3803G15QDCKREP	(-40, 125)	0.58	100	NU
		TPS3803G15QDCKRQ1	(-40, 125)	0.29		
	5	TPS3805H33MDCKREP	(-55, 125)	0.97	185	U
		TPS3805H33DCKR	(-40, 85)	0.34		
	6	TPS3805H33QDCKREP	(-40, 125)	NA	NA	NU
		TPS3805H33QDCKRQ1	(-40, 125)	0.40		
Voltage Regulator	1	TL1431QDREP	(-40, 125)	1.62	200	NU
		TL1431QDR	(-40, 125)	0.54		
	2	TLC7701QPWREP	(-40, 125)	3.02	331	NU
		TLC7701QPWR	(-40, 125)	0.70		
	3	TLC7705QPWREP	(-40, 125)	3.02	331	NU
		TLC7705QPWR	(-40, 125)	0.70		
	4	TLC7733QPWREP	(-40, 125)	3.02	236	NU
		TLC7733QPWR	(-40, 125)	0.90		
	5	TPS3307-18MDREP	(-55, 125)	2.07	97	U
		TPS3307-18DR	(-40, 85)	1.05		
	6	TPS75201QPWPREP	(-40, 125)	3.83	113	NU
		TPS75201QPWPR	(-40, 125)	1.80		
	7	TPS75215QPWPREP	(-40, 125)	3.83	113	NU
		TPS75215QPWPR	(-40, 125)	1.80		
	8	TPS75218QPWPREP	(-40, 125)	3.83	113	NU
		TPS75218QPWPR	(-40, 125)	1.80		
	9	TPS75225QPWPREP	(-40, 125)	3.83	113	NU
		TPS75225QPWPR	(-40, 125)	1.80		
	10	TPS75233QPWPREP	(-40, 125)	3.83	113	NU
		TPS75233QPWPR	(-40, 125)	1.80		
	11	TPS75301QPWPREP	(-40, 125)	3.62	113	NU
		TPS75301QPWPR	(-40, 125)	1.70		
	12	TPS75315QPWPREP	(-40, 125)	3.62	113	NU
		TPS75315QPWPR	(-40, 125)	1.70		
	13	TPS75318QPWPREP	(-40, 125)	3.62	113	NU
		TPS75318QPWPR	(-40, 125)	1.70		
	14	TPS75325QPWPREP	(-40, 125)	3.62	113	NU
		TPS75325QPWPR	(-40, 125)	1.70		
	15	TPS75333QPWPREP	(-40, 125)	3.62	113	NU

Device	**Item No.**	**Part No. (EP/Equivalent COTS)**	**ROC Temperature Range (°C)**	**Cost Per Unit (US $)**	**Cost Percentage Difference (%)**	**Uprated/ Not Uprated**
Voltage Regulator		TPS75333QPWPR	(-40, 125)	1.70		
	16	TPS76701QPWPREP	(-40, 125)	2.35	114	NU
		TPS76701QPWPR	(-40, 125)	1.10		
	17	TPS76715QPWPREP	(-40, 125)	2.35	114	NU
		TPS76715QPWPR	(-40, 125)	1.10		
	18	TPS76718QPWPREP	(-40, 125)	2.35	114	NU
		TPS76718QPWPR	(-40, 125)	1.10		
	19	TPS76725QPWPREP	(-40, 125)	2.35	114	NU
		TPS76725QPWPR	(-40, 125)	1.10		
	20	TPS76733QPWPREP	(-40, 125)	2.35	114	NU
		TPS76733QPWPR	(-40, 125)	1.10		
	21	TPS76750QPWPREP	(-40, 125)	2.35	114	NU
		TPS76750QPWPR	(-40, 125)	1.10		
	22	TPS76801QPWPREP	(-40, 125)	2.25	150	NU
		TPS76801QPWPR	(-40, 125)	0.90		
	23	TPS76815QPWPREP	(-40, 125)	2.25	150	NU
		TPS76815QPWPR	(-40, 125)	0.90		
	24	TPS76818QPWPREP	(-40, 125)	2.25	150	NU
		TPS76818QPWPR	(-40, 125)	0.90		
	25	TPS76825QPWPREP	(-40, 125)	2.25	150	NU
		TPS76825QPWPR	(-40, 125)	0.90		
	26	TPS76833QPWPREP	(-40, 125)	2.25	150	NU
		TPS76833QPWPR	(-40, 125)	0.90		
	27	TPS76850QPWPREP	(-40, 125)	2.25	150	NU
		TPS76850QPWPR	(-40, 125)	0.90		
	28	TPS77501MPWPREP	(-55, 125)	1.97	107	U
		TPS77501PWPR	(-40, 125)	0.95		
	29	TPS77515MPWPREP	(-55, 125)	1.97	107	U
		TPS77515PWPR	(-40, 125)	0.95		
	30	TPS77518MPWPREP	(-55, 125)	1.97	107	U
		TPS77518PWPR	(-40, 125)	0.95		
	31	TPS77525MPWPREP	(-55, 125)	1.97	107	U
		TPS77525PWPR	(-40, 125)	0.95		
	32	TPS77533MPWPREP	(-55, 125)	1.97	107	U
		TPS77533PWPR	(-40, 125)	0.95		
	33	TPS77601QPWPREP	(-40, 125)	1.87	167	NU
		TPS77601PWPR	(-40, 125)	0.70		
	34	TPS77615QPWPREP	(-40, 125)	1.87	167	NU
		TPS77615PWPR	(-40, 125)	0.70		
	35	TPS77618QPWPREP	(-40, 125)	1.87	167	NU
		TPS77618PWPR	(-40, 125)	0.70		
	36	TPS77625QPWPREP	(-40, 125)	1.87	167	NU
		TPS77625PWPR	(-40, 125)	0.70		
	37	TPS77633QPWPREP	(-40, 125)	1.87	167	NU
		TPS77633PWPR	(-40, 125)	0.70		
	38	TPS79101DBVREP	(-40, 125)	0.85	113	NU
		TPS79101DBVR	(-40, 125)	0.40		
	39	TPS79118DBVREP	(-40, 125)	0.85	113	NU
		TPS79118DBVR	(-40, 125)	0.40		
	40	TPS79133DBVREP	(-40, 125)	0.85	113	NU
		TPS79133DBVR	(-40, 125)	0.40		
	41	TPS79147DBVREP	(-40, 125)	0.85	113	NU
		TPS79147DBVR	(-40, 125)	0.40		
	42	TPS79301DBVREP	(-40, 125)	0.91	225	U
		TPS79301DBVR	(-40, 85)	0.28		

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
Voltage Regulator	43	TPS79318DBVREP	(-40, 125)	0.91	225	U
		TPS79318DBVR	(-40, 85)	0.28		
	44	TPS79325DBVREP	(-40, 125)	0.91	225	U
		TPS79325DBVR	(-40, 85)	0.28		
	45	TPS79333DBVREP	(-40, 125)	0.91	225	U
		TPS79333DBVR	(-40, 85)	0.28		
	46	TPS793475DBVREP	(-40, 125)	0.91	225	U
		TPS793475DBVR	(-40, 85)	0.28		
	47	UC1842AMDREP	(-55, 125)	2.03	126	U
		UC2842AD	(-40, 85)	0.90		
	48	UC1843AMDREP	(-55, 125)	2.03	126	U
		UC2843AD	(-40, 85)	0.90		
	49	UC1844AMDREP	(-55, 125)	2.42	69	U
		UC2844AQDR	(-40, 125)	1.43		
	50	UC1845AMDREP	(-55, 125)	2.03	93	U
		UC2845AD	(-40, 85)	1.05		
	51	UC2832TDWEP	(-40, 105)	5.04	58	U
		UC2832DW	(-25, 85)	3.20		
	52	UC2832TDWREP	(-40, 105)	5.04	58	U
		UC2832DWTR	(-25, 85)	3.20		
	53	UCC2800QDREP	(-40, 125)	3.26	81	U
		UCC2800D	(-40, 85)	1.80		
	54	UCC2801QDREP	(-40, 125)	3.26	81	U
		UCC2801D	(-40, 85)	1.80		
	55	UCC2802QDREP	(-40, 125)	3.26	81	U
		UCC2802D	(-40, 85)	1.80		
	56	UCC2803QDREP	(-40, 125)	3.00	67	U
		UCC2803D	(-40, 85)	1.80		
	57	UCC2804QDREP	(-40, 125)	3.00	67	U
		UCC2804D	(-40, 85)	1.80		
	58	UCC2805QDREP	(-40, 125)	3.25	81	U
		UCC2805D	(-40, 85)	1.80		
	59	UCC2808AQDR-1EP	(-40, 125)	2.84	110	U
		UCC2808AD-1	(-40, 85)	1.35		
	60	UCC2808AQDR-2EP	(-40, 125)	2.84	110	U
		UCC2808AD-2	(-40, 85)	1.35		
ABT based Logic Parts	1	SN74ABTH32245MPZEP	(-55, 125)	20.38	-3	U
		SN74ABTH32245PZ	(-40, 85)	20.90		
	2	SN74ABTH32543MPZEP	(-55, 125)	22.52	-3	U
		SN74ABTH32543PZ	(-40, 85)	23.10		
	3	SN74ABT245BMDBREP	(-55, 125)	1.20	200	U
		SN74ABT245BDBR	(-40, 85)	0.40		
	4	SN74ABT541BIPWREP	(-40, 85)	2.73	469	NU
		SN74ABT541BPWR	(-40, 85)	0.48		
AC	1	SN74AC04MDREP	(-55, 125)	0.68	423	U
		SN74AC04DR	(-40, 85)	0.13		
	2	SN74AC08MDREP	(-55, 125)	0.68	423	U
		SN74AC08DR	(-40, 85)	0.13		
	3	SN74AC11IPWREP	(-40, 85)	0.44	193	NU
		SN74AC11PWR	(-40, 85)	0.15		
	4	SN74AC244MDWREP	(-55, 125)	2.02	477	U
		SN74AC244DWR	(-40, 85)	0.35		
	5	SN74AC245IDWREP	(-40, 85)	1.24	254	NU
		SN74AC245DWR	(-40, 85)	0.35		
	6	SN74AC32MDREP	(-55, 125)	0.68	423	U

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
		SN74AC32DR	(-40, 85)	0.13		
	7	SN74AC373MDWREP	(-55, 125)	2.33	580	U
		SN74AC373DWR	(-40, 85)	0.35		
	8	SN74AC74MDREP	(-55, 125)	0.68	423	U
		SN74AC74DR	(-40, 85)	0.13		
ACT	1	SN74ACT04IDREP	(-40, 85)	0.60	362	NU
		SN74ACT04DR	(-40, 85)	0.13		
	2	SN74ACT08IDREP	(-40, 85)	0.60	362	NU
		SN74ACT08DR	(-40, 85)	0.13		
	3	SN74ACT16245QDLREP	(-40, 125)	3.39	208	U
		74ACT16245DLR	(-40, 85)	1.10		
	4	SN74ACT16373QDLREP	(-40, 125)	3.46	215	U
		74ACT16373DLR	(-40, 85)	1.10		
	5	SN74ACT16374QDLREP	(-40, 125)	3.46	215	U
		74ACT16374DLR	(-40, 85)	1.10		
	6	SN74ACT244IDWREP	(-40, 85)	1.24	254	NU
		SN74ACT244DWR	(-40, 85)	0.35		
	7	SN74ACT244MDWREP	(-55, 125)	2.02	477	U
		SN74ACT244DWR	(-40, 85)	0.35		
	8	SN74ACT74MDREP	(-55, 125)	0.68	423	U
		SN74ACT74DR	(-40, 85)	0.13		
ADC	1	TLV1548QDBREP	(-40, 125)	4.36	78	U
		TLV1548IDBR	(-40, 85)	2.45		
AHC	1	SN74AHC00MDREP	(-55, 125)	0.54	260	U
		SN74AHC00DR	(-40, 85)	0.15		
	2	SN74AHC00MPWREP	(-55, 125)	0.54	260	U
		SN74AHC00PWR	(-40, 85)	0.15		
	3	SN74AHC02MPWREP	(-55, 125)	0.55	267	U
		SN74AHC02PWR	(-40, 85)	0.15		
	4	SN74AHC04MDREP	(-55, 125)	0.55	150	U
		SN74AHC04QDR	(-40, 125)	0.22		
	5	SN74AHC04MPWREP	(-55, 125)	0.55	150	U
		SN74AHC04QPWR	(-40, 125)	0.22		
	6	SN74AHC08MDREP	(-55, 125)	0.55	267	U
		SN74AHC08DR	(-40, 85)	0.15		
	7	SN74AHC08MPWREP	(-55, 125)	0.55	244	U
		SN74AHC08PWR	(-40, 85)	0.16		
	8	SN74AHC125MDREP	(-55, 125)	0.66	144	U
		SN74AHC125QDR	(-40, 125)	0.27		
	9	SN74AHC125MPWREP	(-55, 125)	0.66	144	U
		SN74AHC125QPWR	(-40, 125)	0.27		
	10	SN74AHC14MDREP	(-55, 125)	0.54	260	U
		SN74AHC14DR	(-40, 85)	0.15		
	11	SN74AHC14MPWREP	(-55, 125)	0.54	260	U
		SN74AHC14PWR	(-40, 85)	0.15		
	12	SN74AHC244MDWREP	(-55, 125)	0.90	165	U
		SN74AHC244QDWR	(-40, 125)	0.34		
	13	SN74AHC244MPWREP	(-55, 125)	0.90	165	U
		SN74AHC244QPWR	(-40, 125)	0.34		
	14	SN74AHC245MDWREP	(-55, 125)	0.90	165	U
		SN74AHC245QDWR	(-40, 125)	0.34		
	15	SN74AHC245MPWREP	(-55, 125)	0.90	165	U
		SN74AHC245QPWR	(-40, 125)	0.34		
	16	SN74AHC32MDREP	(-55, 125)	0.55	267	U
		SN74AHC32DR	(-40, 85)	0.15		

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
	17	SN74AHC32MPWREP	(-55, 125)	0.55	267	U
		SN74AHC32PWR	(-40, 85)	0.15		
	18	SN74AHC74MDREP	(-55, 125)	0.55	267	U
		SN74AHC74DR	(-40, 85)	0.15		
	19	SN74AHC74MPWREP	(-55, 125)	0.55	267	U
		SN74AHC74PWR	(-40, 125)	0.15		
	20	SN74AHCT74MDREP	(-55, 125)	0.55	267	U
		SN74AHCT74DR	(-40, 85)	0.15		
	21	SN74AHCT74MPWREP	(-55, 125)	0.55	267	U
		SN74AHCT74PWR	(-40, 85)	0.15		
AHCT	1	SN74AHCT00MDREP	(-55, 125)	0.55	267	U
		SN74AHCT00DR	(-40, 85)	0.15		
	2	SN74AHCT00MPWREP	(-55, 125)	0.55	267	U
		SN74AHCT00PWR	(-40, 85)	0.15		
	3	SN74AHCT08MDREP	(-55, 125)	0.55	267	U
		SN74AHCT08DR	(-40, 85)	0.15		
	4	SN74AHCT08MPWREP	(-55, 125)	0.55	267	U
		SN74AHCT08PWR	(-40, 85)	0.15		
	5	SN74AHCT125QDREP	(-40, 125)	0.30	25	U
		SN74AHCT125DR	(-40, 85)	0.24		
	6	SN74AHCT125QPWREP	(-40, 125)	0.30	25	U
		SN74AHCT125PWR	(-40, 85)	0.24		
	7	SN74AHCT126QDREP	(-40, 125)	0.24	0	U
		SN74AHCT126DR	(-40, 85)	0.24		
	8	SN74AHCT126QPWREP	(-40, 125)	0.24	0	U
		SN74AHCT126PWR	(-40, 85)	0.24		
	9	SN74AHCT138MDREP	(-55, 125)	0.66	175	U
		SN74AHCT138DR	(-40, 85)	0.24		
	10	SN74AHCT138MPWREP	(-55, 125)	0.66	175	U
		SN74AHCT138PWR	(-40, 85)	0.24		
	11	SN74AHCT14MDREP	(-55, 125)	0.55	267	U
		SN74AHCT14DR	(-40, 85)	0.15		
	12	SN74AHCT14MPWREP	(-55, 125)	0.55	267	U
		SN74AHCT14PWR	(-40, 85)	0.15		
	13	SN74AHCT244MDWREP	(-55, 125)	0.90	181	U
		SN74AHCT244QDWR	(-40, 125)	0.32		
	14	SN74AHCT244MPWREP	(-55, 125)	0.90	181	U
		SN74AHCT244QPWR	(-40, 125)	0.32		
	15	SN74AHCT32MDREP	(-55, 125)	0.55	150	U
		SN74AHCT32QDR	(-40, 125)	0.22		
	16	SN74AHCT32MPWREP	(-55, 125)	0.55	150	U
		SN74AHCT32QPWR	(-40, 125)	0.22		
	17	SN74AHCT541IDWREP	(-40, 85)	0.66	113	NU
		SN74AHCT541DWR	(-40, 85)	0.31		
ALVC	1	CALVC164245IDGGREP	(-40, 85)	2.97	200	NU
		SN74ALVC164245DGGR	(-40, 85)	0.99		
	2	CALVC164245IDLREP	(-40, 85)	2.97	200	NU
		SN74ALVC164245DLR	(-40, 85)	0.99		
	3	SN74ALVC00IDREP	(-40, 85)	0.96	433	NU
		SN74ALVC00DR	(-40, 85)	0.18		
	4	SN74ALVC08IDREP	(-40, 85)	0.96	433	NU
		SN74ALVC08DR	(-40, 85)	0.18		
	5	SN74ALVC244IPWREP	(-40, 85)	1.60	433	NU
		SN74ALVC244PWR	(-40, 85)	0.30		
HC	1	CD74HC08QM96EP	(-40, 125)	0.27	80	NU

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
		CD74HC08M96	(-55, 125)	0.15		
	2	CD74HC40103QM96EP	(-40, 125)	0.80	46	NU
		CD74HC40103M96	(-55, 125)	0.55		
	3	CD74HC4017QM96EP	(-40, 125)	0.90	190	NU
		CD74HC4017M96	(-55, 125)	0.31		
	4	CD74HC4017QPWREP	(-40, 125)	0.90	190	NU
		CD74HC4017PWR	(-55, 125)	0.31		
	5	CD74HC4051MM96EP	(-55, 125)	1.09	354	NU
		CD74HC4051M96	(-55, 125)	0.24		
	6	SN74HC02QPWREP	(-40, 125)	0.27	80	U
		SN74HC02PWR	(-40, 85)	0.15		
	7	SN74HC10QDREP	(-40, 125)	0.27	80	U
		SN74HC10DR	(-40, 85)	0.15		
	8	SN74HC10QPWREP	(-40, 125)	0.27	80	U
		SN74HC10PWR	(-40, 85)	0.15		
	9	SN74HC165QDREP	(-40, 125)	0.50	108	U
		SN74HC165DR	(-40, 85)	0.24		
	10	SN74HC165QPWREP	(-40, 125)	0.50	108	U
		SN74HC165PWR	(-40, 85)	0.24		
	11	SN74HC166AIDREP	(-40, 85)	0.50	108	NU
		SN74HC166DR	(-40, 85)	0.24		
	12	SN74HC244MDWREP	(-55, 125)	0.82	149	U
		SN74HC244DWR	(-40, 85)	0.33		
	13	SN74HC244QDWREP	(-40, 125)	0.47	42	U
		SN74HC244DWR	(-40, 85)	0.33		
	14	SN74HC244QPWREP	(-40, 125)	0.47	42	U
		SN74HC244PWR	(-40, 85)	0.33		
	15	SN74HC253QDREP	(-40, 125)	0.50	92	U
		SN74HC253DR	(-40, 85)	0.26		
HCT	1	CD74HCT574QM96EP	(-40, 125)	2.03	515	NU
		CD74HCT574M96	(-55, 125)	0.33		
	2	CD74HCT574QPWREP	(-40, 125)	2.03	464	NU
		CD74HCT574PWR	(-55, 125)	0.36		
	3	SN74HCT04IDREP	(-40, 85)	0.33	120	NU
		SN74HCT04DR	(-40, 85)	0.15		
	4	SN74HCT244QPWREP	(-40, 125)	0.53	61	U
		SN74HCT244PWR	(-40, 85)	0.33		
LV	1	SN74LV04ATPWREP	(-40, 105)	1.69	1027	U
		SN74LV04APWR	(-40, 85)	0.15		
	2	SN74LV08ATPWREP	(-40, 105)	0.55	224	U
		SN74LV08APWR	(-40, 85)	0.17		
	3	SN74LV11ATPWREP	(-40, 105)	1.69	412	U
		SN74LV11APWR	(-40, 85)	0.33		
	4	SN74LV123ATPWREP	(-40, 105)	0.90	246	U
		SN74LV123APWR	(-40, 85)	0.26		
	5	SN74LV14ATPWREP	(-40, 105)	0.55	224	U
		SN74LV14APWR	(-40, 85)	0.17		
	6	SN74LV32ATPWREP	(-40, 105)	2.30	1253	U
		SN74LV32APWR	(-40, 85)	0.17		
	7	SN74LV374ATPWREP	(-40, 105)	0.90	246	U
		SN74LV374APWR	(-40, 85)	0.26		
	8	SN74LV393ATPWREP	(-40, 105)	4.12	649	U
		SN74LV393APWR	(-40, 85)	0.55		
	9	SN74LV4051ATDREP	(-40, 105)	8.24	1398	U
		SN74LV4051ADR	(-40, 85)	0.55		

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
	10	SN74LV4051ATPWREP	(-40, 105)	1.21	120	U
		SN74LV4051APWR	(-40, 85)	0.55		
	11	SN74LV4052ATDREP	(-40, 105)	8.24	1398	U
		SN74LV4052ADR	(-40, 85)	0.55		
	12	SN74LV4052ATPWREP	(-40, 105)	1.21	120	U
		SN74LV4052APWR	(-40, 85)	0.55		
	13	SN74LV4053ATDREP	(-40, 105)	8.24	1398	U
		SN74LV4053ADR	(-40, 85)	0.55		
	14	SN74LV4053ATPWREP	(-40, 105)	1.21	120	U
		SN74LV4053APWR	(-40, 85)	0.55		
	15	SN74LV595AIPWREP	(-40, 85)	7.95	1400	NU
		SN74LV595APWR	(-40, 85)	0.53		
	16	SN74LV86ATPWREP	(-40, 105)	3.96	2100	U
		SN74LV86APWR	(-40, 85)	0.18		
LVC	1	CLVC16244AIDGGREP	(-40, 85)	2.76	229	NU
		SN74LVC16244ADGGR	(-40, 85)	0.84		
	2	SN74LVC00AQDREP	(-40, 125)	0.72	380	NU
		SN74LVC00ADR	(-40, 125)	0.15		
	3	SN74LVC00AQPWREP	(-40, 125)	0.72	380	NU
		SN74LVC00APWR	(-40, 125)	0.15		
	4	SN74LVC04AQDREP	(-40, 125)	0.73	387	NU
		SN74LVC04ADR	(-40, 125)	0.15		
	5	SN74LVC04AQPWREP	(-40, 125)	0.73	387	NU
		SN74LVC04APWR	(-40, 125)	0.15		
	6	SN74LVC07AIPWREP	(-40, 85)	0.74	393	NU
		SN74LVC07APWR	(-40, 85)	0.15		
	7	CLVC1G125IDCKREP	(-40, 85)	0.48	269	NU
		SN74LVC1G125DCKR	(-40, 85)	0.13		
	8	CLVC1G126IDCKREP	(-40, 85)	0.48	269	NU
		SN74LVC1G126DCKR	(-40, 85)	0.13		
	9	SN74LVC08AQDREP	(-40, 125)	0.74	393	NU
		SN74LVC08ADR	(-40, 125)	0.15		
	10	SN74LVC08AQPWREP	(-40, 125)	0.74	393	NU
		SN74LVC08APWR	(-40, 125)	0.15		
	11	SN74LVC125AIPWREP	(-40, 85)	0.89	345	NU
		SN74LVC125APWR	(-40, 125)	0.20		
	12	SN74LVC138AQDREP	(-40, 125)	0.82	345	U
		SN74LVC138ADR	(-40, 85)	0.20		
	13	SN74LVC138AQPWREP	(-40, 125)	0.82	345	U
		SN74LVC138APWR	(-40, 85)	0.20		
	14	SN74LVC14AQDREP	(-40, 125)	0.99	560	NU
		SN74LVC14ADR	(-40, 125)	0.15		
	15	SN74LVC14AQPWREP	(-40, 125)	0.99	560	NU
		SN74LVC14APWR	(-40, 125)	0.15		
	16	SN74LVC157AQDREP	(-40, 125)	1.92	860	U
		SN74LVC157ADR	(-40, 85)	0.20		
	17	SN74LVC157AQPWREP	(-40, 125)	1.92	860	U
		SN74LVC157APWR	(-40, 85)	0.20		
	18	SN74LVC1G00IDCKREP	(-40, 85)	0.48	300	NU
		SN74LVC1G00DCKR	(-40, 85)	0.12		
LVC	19	SN74LVC1G08IDCKREP	(-40, 85)	0.48	300	NU
		SN74LVC1G08DCKR	(-40, 85)	0.12		
	20	SN74LVC1G32IDCKREP	(-40, 85)	0.48	300	NU
		SN74LVC1G32DCKR	(-40, 85)	0.12		
	21	SN74LVC1G97IDCKREP	(-40, 85)	0.48	269	NU

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
		SN74LVC1G97DCKR	(-40, 85)	0.13		
	22	SN74LVC1G98IDCKREP	(-40, 85)	0.48	269	NU
		SN74LVC1G98DCKR	(-40, 85)	0.13		
	23	SN74LVC245AIPWREP	(-40, 85)	1.73	424	NU
		SN74LVC245APWR	(-40, 85)	0.33		
	24	SN74LVC257AQDREP	(-40, 125)	1.89	759	U
		SN74LVC257ADR	(-40, 85)	0.22		
	25	SN74LVC257AQPWREP	(-40, 125)	1.89	627	U
		SN74LVC257APWR	(-40, 85)	0.26		
	26	SN74LVC32AQDREP	(-40, 125)	0.74	393	U
		SN74LVC32ADR	(-40, 85)	0.15		
	27	SN74LVC32AQPWREP	(-40, 125)	0.74	393	U
		SN74LVC32APWR	(-40, 85)	0.15		
	28	SN74LVC373AQDWREP	(-40, 125)	1.95	650	U
		SN74LVC373ADWR	(-40, 85)	0.26		
	29	SN74LVC373AQPWREP	(-40, 125)	1.95	650	U
		SN74LVC373APWR	(-40, 85)	0.26		
	30	SN74LVC374AQDWREP	(-40, 125)	1.95	650	U
		SN74LVC374ADWR	(-40, 85)	0.26		
	31	SN74LVC374AQPWREP	(-40, 125)	1.95	650	U
		SN74LVC374APWR	(-40, 85)	0.26		
	32	SN74LVC4245AIPWREP	(-40, 85)	2.36	258	NU
		SN74LVC4245APWR	(-40, 85)	0.66		
	33	SN74LVC540AQDWREP	(-40, 125)	1.95	650	U
		SN74LVC540ADWR	(-40, 85)	0.26		
	34	SN74LVC540AQPWREP	(-40, 125)	1.95	650	U
		SN74LVC540APWR	(-40, 85)	0.26		
	35	SN74LVC541AQDWREP	(-40, 125)	1.95	650	U
		SN74LVC541ADWR	(-40, 85)	0.26		
	36	SN74LVC541AQPWREP	(-40, 125)	1.95	650	U
		SN74LVC541APWR	(-40, 85)	0.26		
	37	SN74LVC573AQDWREP	(-40, 125)	1.95	650	U
		SN74LVC573ADWR	(-40, 85)	0.26		
	38	SN74LVC573AQPWREP	(-40, 125)	1.95	650	U
		SN74LVC573APWR	(-40, 85)	0.26		
	39	SN74LVC574AQDWREP	(-40, 125)	1.95	650	U
		SN74LVC574ADWR	(-40, 85)	0.26		
	40	SN74LVC574AQPWREP	(-40, 125)	1.95	650	U
		SN74LVC574APWR	(-40, 85)	0.26		
	41	SN74LVC74AQDREP	(-40, 125)	0.99	560	U
		SN74LVC74ADR	(-40, 85)	0.15		
	42	SN74LVC74AQPWREP	(-40, 125)	0.99	560	U
		SN74LVC74APWR	(-40, 85)	0.15		
	43	SN74LVC86AQDREP	(-40, 125)	0.74	393	NU
		SN74LVC86ADR	(-40, 125)	0.15		
	44	SN74LVC86AQPWREP	(-40, 125)	0.74	393	NU
		SN74LVC86APWR	(-40, 125)	0.15		
LVCC	1	CLVCC3245AIDBREP	(-40, 85)	2.31	200	NU
		SN74LVCC3245ADBR	(-40, 85)	0.77		
	2	CLVCC3245AIDWREP	(-40, 85)	2.31	200	NU
		SN74LVCC3245ADWR	(-40, 85)	0.77		
	3	CLVCC3245AIPWREP	(-40, 85)	2.31	200	NU
		SN74LVCC3245APWR	(-40, 85)	0.77		
LVCH	1	CALVCH16245IDLREP	(-40, 85)	6.74	513	NU
		SN74ALVCH16245DLR	(-40, 85)	1.10		

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
	2	CLVCH16652AIDGGREP	(-40, 85)	4.12	134	NU
		SN74LVCH16652ADGGR	(-40, 85)	1.76		
LVT	1	SN74LVT125QPWREP	(-40, 125)	3.52	665	U
		SN74LVT125PWR	(-40, 85)	0.46		
	2	SN74LVT8980AIDWREP	(-40, 85)	8.62	35	NU
		SN74LVT8980ADWR	(-40, 85)	6.38		
	3	SN74LVT8996IPWREP	(-40, 85)	7.60	18	NU
		SN74LVT8996PWR	(-40, 85)	6.44		
LVTH	1	8V182512IDGGREP	(-40, 85)	8.61	31	NU
		SN74LVTH182512DGGR	(-40, 85)	6.60		
	2	8V18502AIPMREP	(-40, 85)	8.61	31	NU
		SN74LVTH18502APMR	(-40, 85)	6.60		
	3	8V18646AIPMREP	(-40, 85)	21.99	22	NU
		SN74LVTH18646APM	(-40, 85)	18.04		
	4	CLVTH162240IDGGREP	(-40, 85)	5.39	513	NU
		SN74LVTH162240DGGR	(-40, 85)	0.88		
	5	CLVTH162244IDGGREP	(-40, 85)	5.39	513	NU
		SN74LVTH162244DGGR	(-40, 85)	0.88		
	6	CLVTH162245IDGGREP	(-40, 85)	5.96	577	NU
		SN74LVTH162245DGGR	(-40, 85)	0.88		
	7	CLVTH16240IDGGREP	(-40, 85)	5.16	486	NU
		SN74LVTH16240DGGR	(-40, 85)	0.88		
	8	CLVTH16244AIDGVREP	(-40, 85)	5.81	560	NU
		SN74LVTH16244ADGVR	(-40, 85)	0.88		
	9	CLVTH16244AIGQLREP	(-40, 85)	5.81	487	NU
		SN74LVTH16244AGQLR	(-40, 85)	0.99		
	10	CLVTH16244AIZQLREP	(-40, 85)	5.81	487	NU
		SN74LVTH16244AZQLR	(-40, 85)	0.99		
	11	CLVTH16244AQDGGREP	(-40, 125)	3.78	330	U
		SN74LVTH16244ADGGR	(-40, 85)	0.88		
	12	CLVTH16244AQDLREP	(-40, 125)	7.39	740	U
		SN74LVTH16244ADLR	(-40, 85)	0.88		
	13	CLVTH16245AIDGVREP	(-40, 85)	5.81	560	NU
		SN74LVTH16245ADGVR	(-40, 85)	0.88		
	14	CLVTH16245AIGQLREP	(-40, 85)	5.81	487	NU
		SN74LVTH16245AGQLR	(-40, 85)	0.99		
	15	CLVTH16245AIZQLREP	(-40, 85)	5.81	487	NU
		SN74LVTH16245AZQLR	(-40, 85)	0.99		
	16	CLVTH16245AQDGGREP	(-40, 125)	1.72	96	U
		SN74LVTH16245ADGGR	(-40, 85)	0.88		
	17	CLVTH16245AQDLREP	(-40, 125)	5.28	500	U
		SN74LVTH16245ADLR	(-40, 85)	0.88		
	18	CLVTH16373IDGGREP	(-40, 85)	5.39	513	NU
		SN74LVTH16373DGGR	(-40, 85)	0.88		
	19	CLVTH16373IDLREP	(-40, 85)	8.29	842	NU
		SN74LVTH16373DLR	(-40, 85)	0.88		
	20	CLVTH16373IGQLREP	(-40, 85)	8.29	737	NU
		SN74LVTH16373GQLR	(-40, 85)	0.99		
	21	CLVTH16373IZQLREP	(-40, 85)	8.29	737	NU
		SN74LVTH16373ZQLR	(-40, 85)	0.99		
	22	CLVTH16374IDGGREP	(-40, 85)	5.39	513	NU
		SN74LVTH16374DGGR	(-40, 85)	0.88		
	23	CLVTH16374IDLREP	(-40, 85)	4.91	458	NU
		SN74LVTH16374DLR	(-40, 85)	0.88		
	24	CLVTH16500IDGGREP	(-40, 85)	6.69	368	NU

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
		SN74LVTH16500DGGR	(-40, 85)	1.43		
	25	CLVTH16501IDGGREP	(-40, 85)	6.69	368	NU
		SN74LVTH16501DGGR	(-40, 85)	1.43		
LVTH	26	CLVTH16543IDGGREP	(-40, 85)	5.32	384	NU
		SN74LVTH16543DGGR	(-40, 85)	1.10		
	27	CLVTH16646IDGGREP	(-40, 85)	5.32	246	NU
		SN74LVTH16646DGGR	(-40, 85)	1.54		
	28	CLVTH16652IDGGREP	(-40, 85)	5.88	155	NU
		SN74LVTH16652DGGR	(-40, 85)	2.31		
	29	CLVTH16835IDGGREP	(-40, 85)	7.09	217	NU
		SN74LVTH16835DGGR	(-40, 85)	2.24		
	30	CLVTH16952IDGGREP	(-40, 85)	6.69	289	NU
		SN74LVTH16952DGGR	(-40, 85)	1.72		
	31	CLVTH32244IGKEREP	(-40, 85)	11.07	823	NU
		SN74LVTH32244GKER	(-40, 85)	1.20		
	32	CLVTH32373IGKEREP	(-40, 85)	7.34	410	NU
		SN74LVTH32373GKER	(-40, 85)	1.44		
	33	CLVTH32374IGKEREP	(-40, 85)	7.34	473	NU
		SN74LVTH32374GKER	(-40, 85)	1.28		
	34	SN74LVTH125IPWREP	(-40, 85)	0.64	107	NU
		SN74LVTH125PWR	(-40, 85)	0.31		
	35	SN74LVTH240IPWREP	(-40, 85)	1.70	221	NU
		SN74LVTH240PWR	(-40, 85)	0.53		
	36	SN74LVTH241IPWREP	(-40, 85)	1.70	221	NU
		SN74LVTH241PWR	(-40, 85)	0.53		
	37	SN74LVTH244AQDBREP	(-40, 125)	0.88	120	U
		SN74LVTH244ADBR	(-40, 85)	0.40		
	38	SN74LVTH244AQPWREP	(-40, 125)	1.72	291	U
		SN74LVTH244APWR	(-40, 85)	0.44		
	39	SN74LVTH245AIPWREP	(-40, 85)	1.93	339	NU
		SN74LVTH245APWR	(-40, 85)	0.44		
	40	SN74LVTH273IPWREP	(-40, 85)	1.77	302	NU
		SN74LVTH273PWR	(-40, 85)	0.44		
	41	SN74LVTH373IPWREP	(-40, 85)	1.77	302	NU
		SN74LVTH373PWR	(-40, 85)	0.44		
	42	SN74LVTH374IPWREP	(-40, 85)	1.77	302	NU
		SN74LVTH374PWR	(-40, 85)	0.44		
	43	SN74LVTH543IPWREP	(-40, 85)	2.33	135	NU
		SN74LVTH543PWR	(-40, 85)	0.99		
	44	SN74LVTH573IPWREP	(-40, 85)	1.93	339	NU
		SN74LVTH573PWR	(-40, 85)	0.44		
	45	SN74LVTH574IPWREP	(-40, 85)	1.93	339	NU
		SN74LVTH574PWR	(-40, 85)	0.44		
	46	SN74LVTH646IPWREP	(-40, 85)	2.66	246	NU
		SN74LVTH646PWR	(-40, 85)	0.77		
	47	SN74LVTH652IPWREP	(-40, 85)	3.23	96	NU
		SN74LVTH652PWR	(-40, 85)	1.65		
UBT	1	CVMEH22501AIDGGREP	(-40, 85)	6.86	424	NU
		SN74VMEH22501ADGGR	(-40, 85)	1.31		
	2	CVMEH22501AIDGVREP	(-40, 85)	6.86	424	NU
		SN74VMEH22501ADGVR	(-40, 85)	1.31		
Clock Driver	1	CDC2351MDBREP	(-55, 125)	7.80	28	U
		CDC2351QDBR	(-40, 125)	6.10		
FIFO	1	SN74V263PZAEP	(-55, 125)	56.82	281	U
		SN74V263-6PZA	(0, 70)	14.91		

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
	2	SN74V273PZAEP	(-55, 125)	59.59	268	U
		SN74V273-6PZA	(0, 70)	16.20		
	3	SN74V283PZAEP	(-55, 125)	62.34	257	U
		SN74V283-6PZA	(0, 70)	17.48		
	4	SN74V293PZAEP	(-55, 125)	65.12	247	U
		SN74V293-6PZA	(0, 70)	18.75		

APPENDIX: B

National Semiconductor (NS) Enhanced Plastic Parts

Device	Item No.	Part No. (EP/Equivalent COTS)	ROC Temperature Range (°C)	Cost Per Unit (US $)	Cost Percentage Difference (%)	Uprated/ Not Uprated
Operational Amplifier	1	LMH6628MAEP	(-40, 85)	3.73	150	NU
		LMH6628MA	(-40, 85)	1.49		
	2	LMH6715MAEP	(-40, 85)	4.23	150	NU
		LMH6715MAEP	(-40, 85)	1.69		
	3	LM2902MEP	(-40, 85)	Not Available	Not Applicable	NU
		LM2902M	(-40, 85)	0.22		
	4	LMC660AIMEP	(-40, 85)	Not Available	Not Applicable	NU
		LMC660AIM	(-40, 85)	0.85		
Output Amplifiers	1	LMH6642MFXEP	(-40, 85)	Not Available	Not Applicable	NU
		LMH6642MFX	(-40, 85)	0.66		
	2	LMH6643MAXEP	(-40, 85)	2.31	200	NU
		LMH6643MAX	(-40, 85)	0.70		
	3	LMH6644MAXEP	(-40, 85)	3.25	150	NU
		LMH6644MAX	(-40, 85)	1.30		
Temperature Sensor	1	LM20CIM7EP	(-55, 130)	Not Available	Not Applicable	NU
		LM20CIM7	(-55, 130)	0.30		
Analog Multiplexer	1	STA400MTEP	(-55, 125)	7.50	Not Applicable	Not Applicable
		STA400MT	Not Available			
Sensor Amplifier	1	LM1815MXEP	(-40, 125)	4.20	180	NU
		LM1815MX	(-40, 125)	1.50		
Frequency-to-Voltage Converter	1	LM2907MX-8EP	(-40, 85)	Not Available	Not Applicable	NU
		LM2907MX-8	(-40, 85)	0.68		
	2	LM2917MXEP	(-40, 85)	Not Available	Not Applicable	NU
		LM2917MX	(-40, 85)	0.76		
Current Regulator	1	LM2936MX-5.0EP	(-40, 125)	Not Available	Not Applicable	NU
		LM2936MX-5.0	(-40, 125)	0.75		
Voltage Regulator	1	LM9074MEP	(-40, 125)	Not Available	Not Applicable	NU
		LM9074M	(-40, 125)	0.61		
	2	LM2670SX-ADJEP	(-40, 125)	4.35	120	NU
		LM2670SX-ADJ	(-40, 125)	1.98		
	3	LM2672MX-ADJEP	(-40, 125)	3.87	120	NU
		LM2672MX-ADJ	(-40, 125)	1.76		
	4	LM2675MX-ADJEP	(-40, 125)	3.86	130	NU
		LM2675MX-ADJ	(-40, 125)	1.68		
	5	LM2676S-5.0EP	(-40, 125)	4.14	120	NU
		LM2676S-5.0	(-40, 125)	1.88		
Switch Mode Regulator	1	LM5000-3MTCEP	(-40, 125)	5.00	150	NU
		LM5000-3MTC	(-40, 125)	2.00		
Switching Regulator	1	LM5007MMEP	(-40, 125)	3.15	200	NU
		LM5007MM	(-40, 125)	1.05		
Low-dropout, Fast-response Regulator	1	LMS1585AIS33EP	(-40, 125)	2.55	200	NU
		LMS1585AIS-3.3	(-40, 125)	0.85		
	2	LMS1585AISADJEP	(-40, 125)	2.55	200	NU
		LMS1585AISADJ	(-40, 125)	0.85		
	3	LMS1587ISXADJEP	(-40, 125)	Not Available	Not Applicable	NU
		LMS1587ISXADJ	(-40, 125)	0.74		
Ultra-low-dropout Regulator	1	LP2966MX3325EP	(-40, 125)	2.37	200	NU
		LP2966IMMX3325	(-40, 125)	0.79		
Comparator	1	LM2901MEP	(-40, 85)	Not Available	Not	NU

Device	**Item No.**	**Part No. (EP/Equivalent COTS)**	**ROC Temperature Range** (°C)	**Cost Per Unit** (US $)	**Cost Percentage Difference (%)**	**Uprated/ Not Uprated**
		LM2901M	(-40, 85)	0.22	Applicable	
	2	LM2903MEP	(-40, 85)	Not Available	Not Applicable	NU
		LM2903M	(-40, 85)	0.22		
Step-Down Voltage Regulator	1	LM2575HVS-5.0EP	(-40, 125)	Not Available	Not Applicable	NU
		LM2575HVS-5.0	(-40, 125)	2.42		
	2	LM2575HVS-ADJEP	(-40, 125)	Not Available	Not Applicable	NU
		LM2575HVS-ADJ	(-40, 125)	2.42		
Negative Low Dropout Adjustable Regulator	1	LM2991SEP	(-40, 125)	Not Available	Not Applicable	NU
	2	LM2991S	(-40, 125)	1.35		
Ultra Low Dropout Linear Regulator	1	LP3962ES-2.5EP	(-40, 125)	Not Available	Not Applicable	NU
		LP3962ES-2.5	(-40, 125)	1.37		
	2	LP3965ES-2.5EP	(-40, 125)	Not Available	Not Applicable	NU
		LP3965ES-2.5	(-40, 125)	1.37		

APPENDIX: C

Diversity in Thermal Ratings Availability

AMR and ROC Both Available (Not equal)	AMR and ROC Both Available (Equal)	Only AMR Available	Only ROC Available	Only Storage Available
Advance Micro Devices Atmel Cypress Linear Technology Intersil IDT Cornell Dubilier Analog Devices (3 of 12) Fairchild Semiconductor (6 of 19) UTMC Maxim Integrated Products (1 of 7) ST Microelectronics (1 of 5) Texas Instruments (2 of 13) Motorola (2 of 3)	Heraeus Sensor Maxim Integrated Device (6 of 7) Texas Instruments (3 of 13) Analog Devices (9 of 12) Fairchild Semiconductor (1 of 19)	Diodes Inc International Rectifier Philips Semiconductor Vishay Semiconductor Vishay Telefunkan ON Semiconductor (28 of 30), Fairchild Semiconductor (11 of 19) ST Microelectronics (1 of 5)	Q-Tech Austria Microsystems Microsemi corp. M-Tron Precision Devices Technitrol Xilinx Motorola (1 of 3) ST Microelectronics (3 of 5) Texas Instruments (8 of 13)	Fairchild Semiconductor (1 of 19) ON Semiconductor (2 of 30)

APPENDIX: D

Diversity in Thermal Resistance Information

	Parts with both θ_{JA} and θ_{JC} Values	**Parts with only θ_{JA} Value**	**Parts with only θ_{JC} Value**	**Parts without thermal resistance values**
Number of parts	40	43	11	59
Manufacturers	IDT UTMC Vishay Semiconductor Xilinx Austria Microsystems International Rectifier (7 of 8) Motorola (1 of 3) ON Semiconductor (4 of 30) Philips Semiconductor (6 of 10) ST Microelectronics (3 of 5) Analog Devices (4 of 12) Fairchild Semiconductor (5 of 19) Microsemi Corp.	Precision Device Texas Instruments (7 of 13) Analog Devices (8 of 12) Diodes Inc. (2 of 9) Fairchild Semiconductor (6 of 19) Motorola (1 of 3) ON Semiconductor (12 of 30) Philips Semiconductor (3 of10)	Infineon Technologies International Rectifier (1 of 8) ON Semiconductor (3 of 30) Diodes Inc. (3 of 9) Philips Semiconductor (1 of 10)	Advanced Micro Devices Atmel Cypress Diodes Inc (4 of 9) Fairchild Semiconductor (8 of 19) Heraeus Sensors Intersil Jumo Linear technology Maxim Integrated Device Motorola (1 of 3) M-Tron ON Semiconductor (11 of 30) Q-Tech ST Microelectronics (2 of 5) Technitrol Texas Instruments (6 of 13) Vishay Telefunken

APPENDIX: E

Parts with Risk Level 2 and 3

Risk Level	Part type	Number of parts	Manufacturer
3	Amplifier	2	Analog Devices
	Analog switch	1	Intersil Corp.
	Diode	1	Philips Semiconductor
	N-channel MOSFET	1	Fairchild Semiconductor
	Comparator	1	Analog Devices
	Flash PLD	1	Xilinx
	EE PLD	1	Xilinx
	SRAM	1	Integrated Device Technology
	Rectifier	1	Vishay Semiconductor
2	Amplifier	1	Analog Devices
	Rectifier	1	Fairchild Semiconductor
	Voltage references	3	Analog Devices
	ADC	1	Analog Devices
	SRAM	1	Cypress Semiconductor
	Comparator	1	ST Microelectronics
	Flip- flop	2	ON Semiconductor
	Comparator	1	Texas Instruments
	Flash PLD	2	Fairchild Semiconductor
	AND-Gate	3	ON Semiconductor
	SRAM	1	Texas Instruments
	Rectifier	3	Fairchild Semiconductor
	Oscillator	1	M-tron
	Controller	1	Austria Microsystems
	EEPROM	1	Atmel
	Inverter	1	Texas Instruments
	SRAM	2	Fairchild Semiconductor
	Operational Amplifier	1	Texas Instruments
	Transistor	5	Fairchild Semiconductor

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