

An Enhanced Approach to Qualifying JANS Radiation Hardness Assurance (RHA) Devices to MIL-PRF-19500

Brian P. Triggs Sr, Dr. Michael Gauthier
SEMICOA Corporation
333 McCormick Avenue
Costa Mesa, CA

Abstract-Many aerospace companies purchase Radiation Hardness Assurance (RHA) devices for use in Space and Military Systems with the assumption that they are guaranteed to the specified total dose levels of their respective designation (part number). Modern program requirements for parts characterization in the total dose environment typically specify a statistical acceptance criterion, larger samples size, and parameter deltas. The methodology for RHA acceptance as specified in MIL-PRF-19500 does not require statistical acceptance and is based solely on a go/no-go approach of a small samples size (in one case, it is a sample size of 1), and acceptance is based on parameter end-points. This gap between the qualifying and using communities is the subject of this paper. An enhanced approach to close this gap is presented with a recommendation for revising the qualification requirements of MIL-PRF-19500.

Index Terms-JANS RHA, MIL-PRF-19500, Statistical Acceptance Criteria

I. INTRODUCTION

Manufacturers of JANS devices can perform radiation testing in accordance with MIL-PRF-19500 to qualify them as RHA components with total dose hardness levels ranging from 3krad(Si) up to 1Mrad(Si) [1]. Once this qualification test data has been certified by the Defense Supply Center, Columbus (DSCC), the part can be sold as a RHA component with a certified hardness level. Many users procure these components and do not perform additional radiation characterization due to the manufacturer's guarantee of radiation hardness. However, these same programs typically have stringent characterization requirements for non-RHA components, which include a statistical acceptance criterion. Furthermore, the sample size and allowable parameter shifts are specified for this characterization. The underlining assumption of the community is that the RHA component would meet or exceed these stringent characterization requirements for non-RHA components. The reality is that the RHA qualification requirements are less stringent than most program requirements and in many cases offers very little assurance of a guaranteed radiation performance.

The qualification requirements for JANS RHA devices as defined in MIL-PRF-19500, Appendix E, specifies the sample size which is a function of the number of die that are produced on each wafer. Table 1 summarizes the sample size requirement for JANS devices, for which qualification is at the wafer level.

Table 1. RHA Sample Size required for qualification [1]

Number of Die per Wafer	Sample Size to be tested per wafer
>4,000	4
>500 but <4,000	2
<500	1

Furthermore, the acceptance of the part as RHA is based on (1) testing the number of samples defined in Table 1 and (2) each sample not exceeding the end-point limits defined in the slash sheet, Group D, Subgroup 2 for the component under test. If all of the samples are within these limits, then the part is acceptable at the radiation level of interest.

Typical program requirements for characterizing parts in the total dose environment usually specify a minimum sample size (at least 5) and the acceptance criterion is based on parameter deltas that are derived from the system's worst case circuit analysis. These deltas define how much the parameter can shift simply due to the effects of radiation. Also, the part's response in the total dose environment must meet these delta limits with a defined level of statistical confidence. Usually this is defined as stating that 99% of the population (of the parameter deltas), with 90% confidence, must remain within the delta limits defined by the worst case circuit analysis. This methodology is referred to as P_S/C using KTL Statistics for which the program will define the level of P_S and C required for parts usage on the program [2].

The difference between the MIL-PRF-19500 qualification and the user's program requirements represents a gap that must be addressed to ensure adequate performance of RHA components. A qualification methodology must be developed for RHA devices that is at least as stringent as program requirements.

II. EXISTING RHA REQUIREMENTS

The requirements for qualifying RHA devices is defined in Appendix E, paragraph E.6.5, of MIL-PRF-19500 [1]. This document defines the levels of radiation, the sample size, and the test method for performing the test [3]. The post radiation performance for each device is presented in the Group D, Subgroup 2, requirements of the slash sheet that defines the component. The Group D, Subgroup 2 requirements define the end-point limits for each parameter following the radiation environment. For most devices, there is only one end-point limit specified for each parameter; that is, the same end-point is used for all levels of radiation. The level of radiation to which the part is qualified is designated in the part number. The letter following the JAN brand quality level and identifiers denotes the level of radiation hardness for the part as presented in Table 2.

Table 2. RHA Levels and Requirements [1]

RHA Designation	Total Ionizing Dose [rad(Si)]
M	3×10^3
D	1×10^4
P	3×10^4
L	5×10^4
R	1×10^5
F	3×10^5
G	5×10^5
H	1×10^6

Also defined in Appendix E is the sample size required for qualification (Table 1). The sample size is a function of the number of die produced from each wafer. For JANS devices, the number of samples presented on Table 1 must be randomly selected from each wafer to be qualified. The post radiation performance for each device is specified in the MIL-PRF-19500/slash sheet that defines the component. The requirements are listed in the Group D, Subgroup 2 table for the part. This table defines the end-point limits for each parameter to be tested. There is only one limit given for each parameter, post radiation. Typically, Breakdown Voltages are not allowed to shift below their minimum limits, leakage currents are allowed to double, gains are cut in half, and saturation and “ON” voltages are allowed to increase by 15%. However, there are some devices where the pre-radiation (Group A) and the post-radiation (Group D) performance of some of the parameters are identical.

III. CUSTOMER REQUIREMENTS

A recent survey of Space and Military Programs indicate that the majority of these programs are utilizing some form of statistical acceptance criteria with respect to radiation characterization of parts in the total dose

environment. The minimum sample size is typically 5 and, in many cases, 10. The parameters used for the acceptance of the parts comes from the system’s worst case circuit analysis and defines how much the part can shift simply due to the effects of radiation. Not surprisingly, the guideline documents used to define program hardness assurance requirements also require statistical acceptance, larger samples size, and parameter deltas in the characterization of components for radiation. Most recently, a guideline was created by The Aerospace Corporation for Parts, Materials, and Processes used in Space System [4] developed with the cooperation of the Aerospace community. This document requires using a statistical approach for parts acceptance in a radiation environment. Unless otherwise stated by the program, this document suggests that a P_s/C of 0.99/90% be used. Also recommended is the use of parameter deltas as acceptance criterion and larger sample size for radiation tests. There are some programs that require even more stringent statistical requirements for part acceptance and use 0.9999/90% for part usage [5].

Many program requirements and guideline documents allow the use of RHA devices without any further radiation characterization of testing. The underlining assumption is that these devices have already been tested, at the wafer level for JANS devices, and that they would meet the characterization requirements of the program. There are a few aerospace companies that perform radiation lot acceptance testing on RHA devices due to the minimal qualification requirements of MIL-PRF-19500.

IV. GAP ANALYSIS

The difference between the MIL-PRF-19500 JANS qualification requirements and most programs for parts characterization in a radiation environment presents a gap that must be closed in order to use RHA devices with confidence on Space and Military Programs. The gap between the qualification requirements of MIL-PRF-19500 JANS and the users is summarized in Table 3.

Table 3. Summary of gap between MIL-PRF-19500 JANS and Users of RHA devices

Qual Metric	MIL-PRF-19500	User’s
Parameter Acceptance	End Points (Group D)	Deltas
Sample Size	1 to 4	5 min 10 typical
Statistics	LTPD*	P_s/C **

*LTPD= the Lot Tolerance Percent Defect

** P_s/C =Probability of Survival (P_s) with Confidence (C)

JANS RHA devices are radiation tested at the wafer level and qualified to a designated level of radiation. The designated level of radiation is defined within its part number. For example, the JANSR2N2222A would be

considered qualified to 100 krad(Si) (see Table 2) and the JANSF2N2222A would be qualified to 300 krad(Si). The users of these parts accept these qualifications as a guarantee to perform at that designated level of radiation. However, the users very seldom will reconcile their program parts characterization requirements with the JANS qualification requirements. They simply accept the guarantee that the part will work at the designated level of radiation on their program.

The approach taken for the JANS RHA qualification follows the Lot Tolerance Percent Defect (LTPD) methodology. According to LTPD Methodology [6], testing 4 parts and accepting with no failures [which is denoted as 4(0)] means that if a lot passes the sampling plan, then one can state with 90% confidence that its failure rate is equal to or less than 58%. Also, testing less devices means that the known failure rate would increase. This does not come close to the level of assurance needed for radiation performance by most users.

The purpose of radiation testing components is to first understand what parameters are shifting with respect to the environment and then to be able to predict, with some level of confidence, how future lots will perform. Using sampling statistics for a sample size of n, the parameters of the device can be measured as a function of radiation [2]. At the radiation level of interest the mean (μ) and standard deviation (σ) of each parameter can be calculated. The underlining assumption of the parameters is that they are random variables, normally distributed. Using the mean and standard deviation for the sample tested, an upper or lower bound for the parameter can be calculated representing P_s of the population with C confidence. This parameter upper (PUB) or lower (PLB) bound can then be compared to the limit for the parameter (P_{LIMIT}) to determine parameter acceptance at the level of radiation tested. This relationship for the parameter upper and lower bound is presented in Equations 1 and 2.

$$PUB = \mu + K(P_s, C, n)\sigma \quad (1)$$

$$PLB = \mu - K(P_s, C, n)\sigma \quad (2)$$

where: PUB is the Parameter Upper Bound,
 PLB is the Parameter Lower Bound,
 μ is the mean of the parameter measured,
 σ is the standard deviation of the parameter measured,
 $K(P_s, C, n)$ is the one-sided tolerance factor for the given P_s , C and n (typically read from a table)

Acceptance of the parameter radiation response would then be made by evaluating the PUB or PLB against the P_{LIMIT} . For parameters that increase with radiation, the Accept/Reject decision would be:

Accept if $PUB \leq P_{LIMIT}$
 Reject if $PUB > P_{LIMIT}$

For parameters that decrease with radiation, the Accept/Reject decision would be:

Accept if $PLB \geq P_{LIMIT}$
 Reject if $PLB < P_{LIMIT}$

Each parameter that was tested for radiation would be analyzed in accordance with this methodology and an Accept/Reject decision would be made. If any of the parameters are rejected, then the entire lot of parts must be rejected.

V. ENHANCED RHA METHODOLOGY

The enhanced methodology for qualifying JANS RHA devices must be more in line with how the parts are being used by the users. The fundamentals of the enhanced approach must be based in a P_s/C Statistical Approach, have increased sample sizes tested in the radiation environment, and use well defined parameter delta's as acceptance criterion (how much the part can shift just due to the effects of radiation). The methodology proposed in the following paragraphs is recommended to be used to update the RHA Qualification Requirements in MIL-PRF-19500.

1. Parameter Delta's

The acceptance criteria for each device will be enhanced to include parameter deltas. That is a measure of how much the part can shift just due to the effects of radiation. Most of this information already exists and can be derived from taking the difference between the Group D, Subgroup 2 and the Group A, Subgroup 2 limits. For gain of bipolar transistors (h_{FE}), the delta will be based on the $1/h_{FE}$ parameter [7], and the allowable $\Delta 1/h_{FE}$ will be calculated using Equation 3.

$$\Delta 1/h_{FE} = [(1/h_{FE-Group D}) - (1/h_{FE-Group A})] \quad (3)$$

Acceptance of the device will be based on both the end-points and the parameter deltas. A device must meet both criteria in order to be qualified as RHA. In addition to this change, the parameter delta could be a function of radiation. This would be more in line with how devices actually respond to radiation.

2. Increased Sample Size

The number of samples required to perform the qualification test would be increased and be a function of how many die are produced on a single wafer. The decision point would be at 4,000 die per wafer. For devices that come from a wafer with greater than 4,000, the number of samples to be irradiated would be 11, no

matter how many wafers are to be qualified. If the device comes from a wafer that produces less than 4,000, it would be in accordance with how many wafers are to be qualified and the number to be irradiated would come from Table 4. The reason for the difference is to allow this qualification to be used for JANS or JANTXV (which requires at least 11 samples per wafer lot).

Table 4. Number of Irradiated Samples for Wafers that produce less than 4,000 die

Number of Wafers to be Qualed	Number of Samples to Be Irradiated
1	11
2	6
3 or greater	5

3. Statistical Acceptance Criteria

The acceptance criteria for each parameter listed in the component slash sheet must be within the limits listed in the Group D, Subgroup 2 Table. The Accept/Reject Criteria will follow the methodology defined in Section IV of this paper, using the PUB and PLB. This will include the End-points and the deltas that will be added for each parameter. The P_S for these calculations will be 0.99 and the C level will be 90%. A table of K factors will be added to Appendix E of MIL-PRF-19500.

VI. SUMMARY

Many programs use RHA components without any additional radiation characterization testing under the assumption that they are as good as the characterization requirements of their programs. The fact is that the RHA requirements currently in MIL-PRF-19500 are not as stringent as many program requirements and provide no statistical confidence of the hardness level. Enhancing the qualification requirements of MIL-PRF-19500 by requiring parameter deltas, increased sample size and an acceptance criterion that is based on a 0.99/90% statistical calculation would provide the guarantee that is needed for such products to be used without any further testing or characterization.

VII. ACKNOWLEDGEMENTS

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