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Design Validation and Reliability Assurance of Electronic Systems Using the Next Generation RGT Models

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ABSTRACT

Arrhenius Accelerated Growth Test (AAGT) models is the next generation accelerated testing models used for design validation and reliability assurance of electronics systems. These models are used in design and manufacturing phases towards reliability enhancement of the system respectively. AAGT Models uses Highly Accelerated Stresses for screening of the components towards uncovering product defects as compared to traditional qualification test methods, these models are used to quickly identify design flaws, latent defects, component selection problems, and manufacturing flaws. The procedure includes thermal dwells and rapid temperature changes while subjecting the test unit to increasing degrees of stress. Dynamic stresses (Pseudo-Random Vibration covering all 6DOF systems) and a combination of thermal and dynamic PSD stresses are used towards quickly precipitating inherent/hidden defects. These Accelerated models are used in the research to qualify active array radar modules like Transmit Receive Modules (TRMs) which will be in used in large numbers for modern radar systems, as compared to a traditional approach that will be difficult and time-consuming to filter these modules individually. To increase the quality and dependability of electronic devices, these accelerated life tests models have been extensively adopted. However, extremely accelerated life tests may only be used as a qualitative approach to assess a product's dependability; they cannot be used to quantify a product's reliability, such as MTBF/MTTF. Consequently, in order to efficiently assess the level of product reliability while improving product reliability in a timely manner. HALT/HASS uses Arrhenius Accelerated Growth Model that is an effective technique used for screening of the module with in short period. This paper discuss in detail with a case study on active array modules deliberating about the test methodology, challenges faced during Using Arrhenius accelerated test models, rapid testing and assessment of these Four channel TRMs used for airborne Fire Control Radar for combat operations.

Keywords: HALT; HASS; AAGT; Accelerated testing; POS; AESA; Four channel TRMs MTTF; Data assessment and FRACAS

NOMENCLATURE

HALT	:	Highly Accelerated Life Testing
HASS	:	Highly Accelerated Stress Screening
POS	:	Proof of Screening
AAGT	:	Arrhenius Accelerated Growth Test
AESA	:	Active Electronically Scanned Array
TRMs	:	Transmit Receive Modules
MTTF	:	Mean Time To Failure
FRACAS	:	Failure Reporting Analysis Corrective Action Systems

1. INTRODUCTION

The conventional Approach used towards design and validation of product reliability is subjecting the product to the field evaluation and collecting the data based on failures followed by redesigning the product accordingly, second approach was qualification test where the product will be subjected to shake and bake test using predefine military standards, in which the equipment/modules will be tested to their operating environmental conditions and once it is passed these test, the unit is declared to be fit and delivered to the customer. This conventional approach has lot of limitation as this independent shake and bake test is not simulating actual field conditions and also in contrary field evaluation test is a time consuming and has various limitation towards sample size and resources.

A unique methodology is introduced in this research manuscript where in by using Accelerated Reliability Growth (AGT) Models such as "Highly accelerated life testing (HALT) and Highly accelerated stress screening (HASS)" a new process is evolved which will be used to quickly uncover product defects and identify the weak links in the design by subjecting the product to these extreme stresses thereby uncovering the failure quickly and helps in component to product reliability. In accelerated testing the failures can be analyzed and product can be redesign in its early/proto design phase, thus building a reliable, rugged and failure free product[1-2].

2. MARKET DEMAND TOWARDS BUILDING QUALITY FIRST TIME RIGHT IN THE PRODUCT

The current challenge is to build quality in the product by

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implementing first time right concept from the design phase to development and production phases, starting from conceptual to production deliverables modules covering all the bands of requirements ranging from general daily consumers to Industrial and Military-Space systems demanding for greater product quality. A high rate of product failure in the consumer market can cost the manufacturer name/resources and goodwill, both of which might take years to regain. Severe failures in industrial markets might lead to costly field service visits or, worse still, prolonged downtime. Product failures in the military sector may lead to mission or life losses. Despite the increased demand for quality, along with other developments, are it harder to uphold current standards. The use of manufacturing subcontractors has expanded, which has been the most difficult development. The "manufacturer" whose name appears on a product is probably depending on a subcontractor, an external resource that the manufacturer has no direct control over. The manufacturer's ability to regulate the quality of the product is further weakened by this subcontractor's dependence on a number of suppliers. Customers will hold the maker accountable if a product fails. The manufacturer is in charge of the product's quality because their name is on it[3].

3. LIMITATIONS OF TRADITIONAL APPROACHES USED TO BUILD PRODUCT RELIABILITY

Modern reliable and sophisticated electronic and electro-mechanical products owe much of their development evaluation process to traditional vibration and temperature testing. The main tenet of this testing approach is to execute the tests while often adjusting the minimum or maximum temperatures and/or vibration levels while only altering one variable at a time. One axis is tested for vibration at a time. The "DUT" is said to have "passed" if it remains operational after being tested in accordance with the test specifications.

A "passing" Result is a successful conclusion. However, contemplating if you give it more thought, it becomes obvious that a "pass" result does not help you identify the product's failure/weak joint. In other words, the engineer or scientist cannot strengthen the product using the conventional test. Furthermore, the test specifications are not representative of real-world operating settings due to the "one-at-a-time" change in ambient factors and the one-dimensional dynamic stress. Because of this, this kind of testing cannot accurately predict how the product will function in the real world. This analysis of conventional environmental analysis is not meant to be a used due to lot of limitation. To build a highly reliable products it is proposed to used soe reliability models and build an accelerated test methodogly such as HALT and HASS testing, in particular, which can lead to greater levels of product quality and dependability[2] and can be replaced with traditional approach of testing which has several flaws[4-5].

4. PROPOSED SOLUTION TOWARDS BUIDLING PRODUCT RELIABILITY - HALT/HASS USING AAGT

System/Subsystem subjected to an accelerated testing will be using AAGT models will be initially subjected to incremental stress testing of climatic and dynamic stresses such as thermal, sine pulse, and PSD random testing during highly-accelerated life testing (HALT). Vibration testing here will be pseudorandom vibration simulating actual field vibration conducting 6DOF stresses with HALT utilizing a random mode of frequencies. The combined stresses of several climatic and dynamic stresses, such as thermal stress and dynamic stress test can be a part of HALT testing. This multi-variable testing strategy offers a more accurate representation of actual field working stress[6-7].

Highly accelerated life testing in contrast to normal testing, aims to mimic product failure. The weakest link inside the product is found when it breaks, allowing engineers to identify the corrective measures that needs to be done to raise system/subsystem performance requirements. The weak component(s) of a product are improved or reinforced after it fails. The product fails once more when it is put through second time for similar stresses with a wider range. Following weakest link is revealed by this. The cycle is repeated until numerous simultaneous failures occur; the product can be manufactured to be more rugged and durable. This methodical technique identifies the areas that need strengthening[8-9].

To ensure that the fundamental design of a product is trustworthy, HALT testing must be done throughout the design process. But it's crucial to keep in mind that the tested units are probably engineering prototypes, and we must make sure that this accelerated stress testing is done on all deliverables produced units after prototyping is finished to make sure that the change from engineering design to production design did not cause a loss in performance. In general, it might view this strategy as being rational from a scientific standpoint fiscally impossible, though. The most frequent concern about accelerated test is however, is that it will be expensive. However, thanks to the concept of innovative testing strategy that has been discovered that the cost of accelerated testing is significantly lower than the cost of deployed system failures, servicing issues, maintenance issues and unwanted claims etc., which result of subpar product quality. Second, we will process the extrapolated data through the reliability growth model (Duane model) in order to achieve a quantitative evaluation of the highly accelerated life test, keeping in mind that the HALT needs to continuously improve the product in order to raise the inherent reliability of the product. Finally, specific cases were employed to further confirm the method's applicability and accuracy.

A shortened version of production quality screening is a continuous screening procedure carried out on normal system/subsystems. Main target of this is not to damage the units/device, instead to confirm that real mass produced units continues to function normally even after being exposed to the environmental cycling employed in the HASS test.

Based on an expert assessment of the accelerated test specifications/limits, the various design margins and its limitations employed in production screening is been developed/evolved. In general we thinks about the usual production scenario of today, one may understand the significance of HASS testing. A vendor sells circuit boards made from supplies acquired from other vendors. The makers of ICs, super components, devices etc., are located across the globe. Subcontractors frequently handle the product's final configuration.

This means that all of the components, materials, and processes that go into creating the end product have a bearing on its quality (or lack thereof). The quality and dependability of the finished product can and do change over time as a result of these components, materials, and processes. HASS testing[1] is the most effective approach to make sure that production units continue to fulfil dependability goals[10-11].

5. METHODS FOR DATA EXTRAPOLATION

It is vital to examine the product's failure mechanism and then modify the product to raise the product's inherent reliability when the highly accelerated life test is conducted as the amount of stress keeps rising and product failures keep coming to light[1]. As the product's inherent reliability rises as a result of this process, the activation energy required to activate the defect also rises. From the standpoint of activation energy, the product's intrinsic reliability will rise incrementally with each upgrade, and the activation energy will rise incrementally as well. The failures have varying activation energies and varying acceleration factors at each stress level. The minimal energy needed to start a specific process is known as activation energy, which is typically represented by the symbol *Ea*. It is frequently used to refer to the bare minimum energy that chemical reactants must possess before they may engage in a chemical reaction. Activation energy, however, refers to the minimal amount of energy necessary to start a temperature-accelerated failure process in the context of semiconductor device reliability[12-13].

A physical event that, if started and allowed enough time to develop, can cause a device to fail is referred to as a failure mechanism. This isn't the same as a device's failure mode, which is a specific kind of failure. The physical phenomenon underlying the failure mode is, in essence, the failure mechanism. Similar failure modes can be caused by dissimilar failure mechanisms, just as a single failure mechanism can lead to a variety of failure modes. Finding the appropriate failure mechanism during failure analysis is essential for ensuring that the issue doesn't recur.

The Accelerated-Arrhenius process explains the scientific dependency between the rate at which a failure mechanism occurs, the temperature, and the failure mechanism's activation energy, must always be brought up in discussions of activation energy[14].

The following is the Arrhenius Eqn:

$$R = \frac{Ea}{k}\left[\frac{1}{T1} - \frac{1}{T2}\right] \qquad (1)$$

where;

R : is the rate at which the failure mechanism occurs,
A : is a constant,
Ea : is the activation energy (ev)
k : is Boltzmann's constant (8.6e-5 eV/K)
T : is the absolute temperature at Deg Kelvin

A failure mechanism's relative propensity to be accelerated by temperature is shown by the activation energy value.

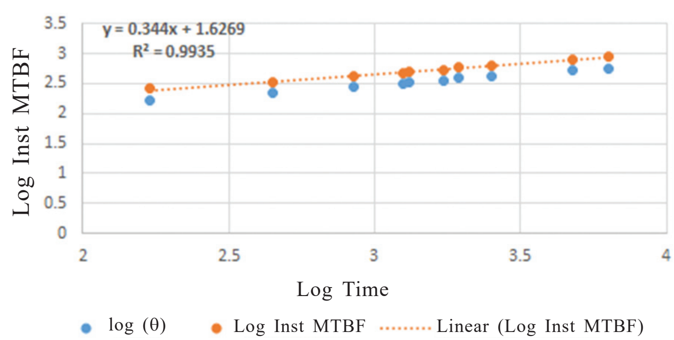
Table 1. Activation energies of some failure mechanisms

Failure mechanism	Accelerating factors	Activation energy
Dir-electric breakdown	Electric field, temperature	0.2-1.0 eV
Corrosion	Humidity, temperature, voltages	0.3-1.1 eV
Electro migration	Temperature, Current Density	0.5-1.2 eV
Au-Al intermetallic growth	Temperature	1.0-1.05 eV
Hot carried injection	Electric field, temperature	-1 eV
Mobile ionic contam	Temperature	1.0-1.05 eV

The activation energy estimates for some of the numerous failure mechanisms frequently seen in the semiconductor industry are shown in Table 1.

6. RELIABILITY GROWTH MODEL - DUANE MODEL EVALUATION

The growth models is chosen for evaluation based on the experiments recorded outcomes during HALT test. This model "DUANE" is the most widely utilized models. The Duane model is advised because this requires few samples at the early stage of development. As a time function model, the Duane model has the potential to anticipate product reliability as well as evaluate it dynamically. The major method employed when the Duane model is used to estimate the product lifespan is parameter estimation, and the most popular method for parameter estimation is least squares estimation. After parameter estimation, the Duane model must be assessed for goodness of fit in order to confirm that the test data closely match the fitted line[15-16].



(Note: Data values not shown due to security concern)

Figure 1. DUANE models –RGT.

Duane model shows actual field test data of TRMs deployed in field in multiple platforms as shown in Fig. 1.

- Duane Model shows the RGT of system showing instantaneous MTBF is above cumulative MTBF
- Duane Assumes development test is done at operating condition, hence it is good model to used for field testing
- Duane takes corrective action and tracked for effectiveness.

7. CASE STUDY AESA QTRMS UNDERGOING HALT/HASS TESTING AIRBORNE FIGHTER CLASS PLATFORM

HALT testing is a destructive test and was successfully performed on four channel TRMs for Airborne Fighter Class Radar for the first time in LRDE, DRDO. This test was carried out at initial design phases during product developmental life cycle, the objective of HALT is to know the operation and destructive limits of the product and also to identify the weak links in the design and address those weak links before the product undergoes mass production and deliver a reliable and rugged product to the user. The HALT/HASS tests reveal design flaws, which may need to be fixed before actual qualification and certification testing in order to make the design more effective. In HALT every stimulus with potential value is used under accelerated test conditions to identify any weak points in the product's design and manufacturing process.

After HALT test these modules go through HASS screening to address manufacturing and latent issues. The HASS screening uses the inputs from HALT and employs the highest stresses; pressures that are well above the operational threshold. Multiple loads are applied simultaneously by HASS, exposing fault precipitation and manufacturing flaws. Correctly, screening using HASS will result in a significant reduction for time spent on screening the production/deliverable unit using conventional approach, thereby leading towards addressing both quality and reliability requirements with the project schedule[17-18].

7.1 SCOPE

The paper discusses in detail the HALT/HASS test methodologies used for X Band QTRMs, along with the screening process, obstacles encountered, and design improvements made by properly implementing FRACAS during HALT/HASS test failures[19-20].

7.2 PROBLEM BRIEFING

The fundamental element of an active phased array is "Transmit/Receive Modules-TRMS". These modules receive the RF signal in transmit (TX) mode, amplify it, and then send the amplified signal to antenna elements. Each T/R Module receives a signal from an antenna element in receive (Rx) mode and amplifies the signal with minimal noise. The Quad-TRM, often known as the QTRM, is a single package that contains four different T/R Modules. The QTRM can be combined with 1:4 ways RF power combiners and is sometimes referred to as QTRM-X (in the X-Band). The QTRM's functional block diagram is shown in Fig. 2.

7.3 HALT Requirement

Prior to qualification testing, the accelerated life testing is done to reveal design flaws in the design. The goal of the design verification testing is to confirm that the design complies with the technical requirements.

7.4 HALT Test Objective

To establish the product's various margins ranging from operating, screening to destructive limits. To identify and address issues with manufacturing processes, mounting procedures, and weak component and product design that may limit the production ESS environment.

7.5 HALT Test

The following shall be included in the HALT/HASS Testing and Analysis Facility:

- Accelerated life test facility "HALT/HASS" chamber as seen in Fig. 3.
- Temp limits: -150 °C to 250 ºC
- Pseudo random (6 DOF) vibration upto 75 grms
- Thermal sensors
- Test jigs
- Transducers

7.6 HALT Test on X QTRMs

The unit is visually inspected prior to and on completion of each test of HALT using optical equipment having a capability of 40x magnification is shown in Fig. 3.

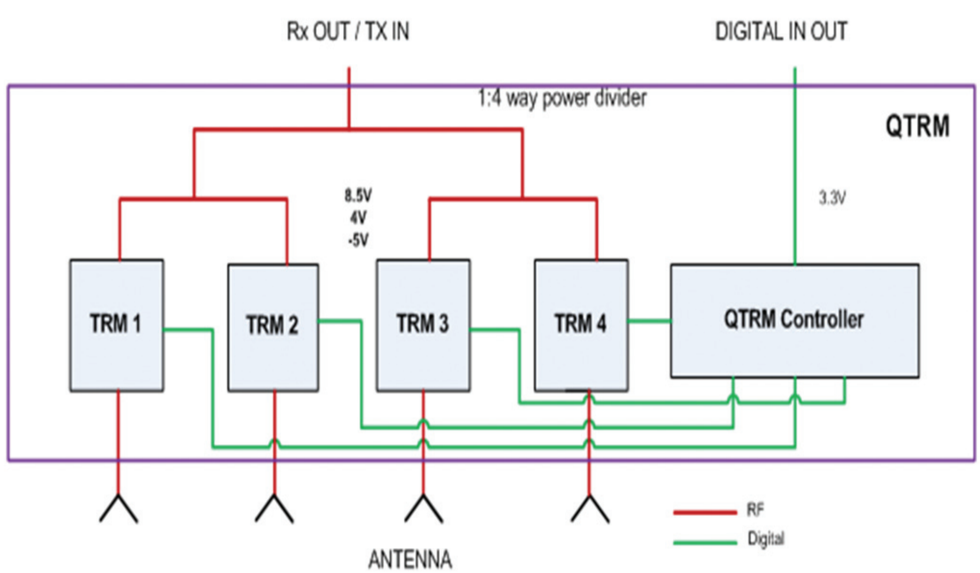


Figure 2. QTRM-X functional blocks.

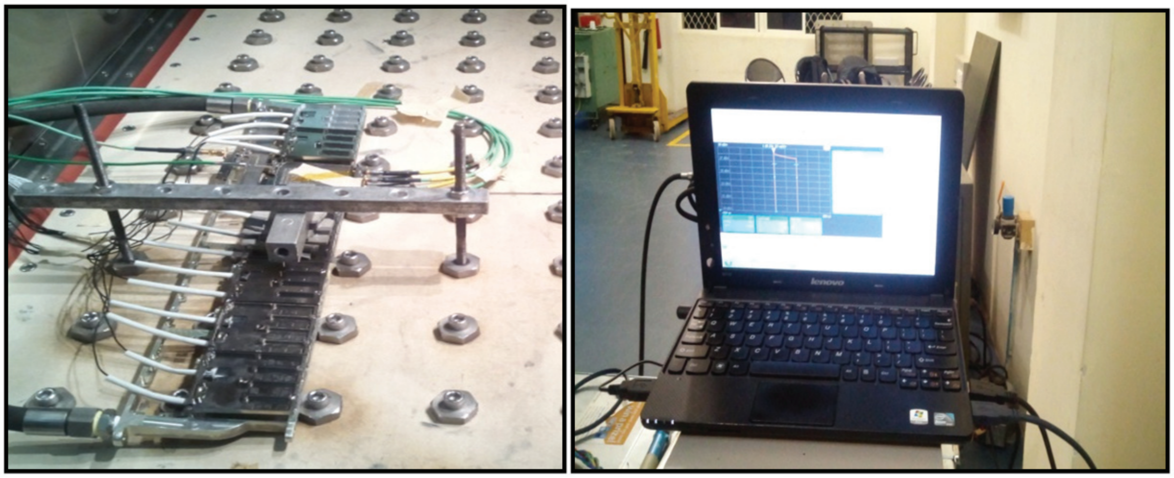


Figure 3. HALT test setup of X QTRMs.

Figure 4. Observation after HALT- Hot step test.

7.7 Challenges Encountered During HALT Test Description

First QTRM mechanical enclosure and bare PCB is undergone HALT design verification test during HALT before actual QTRM is as shown in Fig. 4. Increasing stress levels progressively, up-to the design limit of the module is main issue of testing; it provides a determination of the safety margin built into the design, possible failure mode and areas where design improvements will be made prior to commencement of the qualification/validation of design[21].

The testing is designed to increase confidence in the ability of the LRU to withstand the storage and operating environments of the specification requirements and to allow incorporation of design improvements in the event of test anomalies.

Table 2 shows Independent HALT test results conducted using AAGT models for various temperature cycles of both positive, negative and vibration limits on QTRMs for airborne radar.

Table 2. HALT test on QTRMs-Airborne fire control radar

Product Spec	U-1 (°C)	U-2 (°C)	U-3 (°C)	U-4 (°C)	U-5 (°C)
UPS	65	65	65	65	65
USL	75-80	70-80	80-85	75-80	77-85
UOL	85-95	85-90	88-93	88-95	90-95
UDL	110-120	100-110	105-115	100-110	110-115
LPS	-40	-40	40	-40	40
LSL	-45 to -55	-51	-53	-50	-55
LOL	-55 to -60	-55	-61	-57	-59
LDL	-65 to -75	-68	-73	-77	-74
Vibration limits	20 Grms	19 Grms	21 Grms	18.5 Grms	21 Grms

7.9 FRACAS–HALT Test Process

- A Micro level opening near the mounting hole at the center of QTRM mechanical housing is seen in 40X Magnifier after the HALT-High temperature step stress test which is shown in Fig. 4, test continued for vibration step stress test
- Observation after HALT Vibration Stepped Process: Top cover lid of QTRM mechanical housing opens after

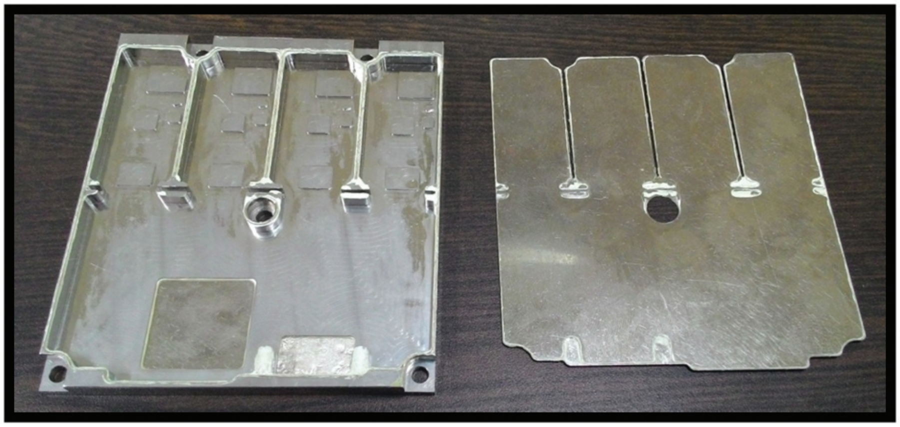


Figure 5. Top lid cover open.

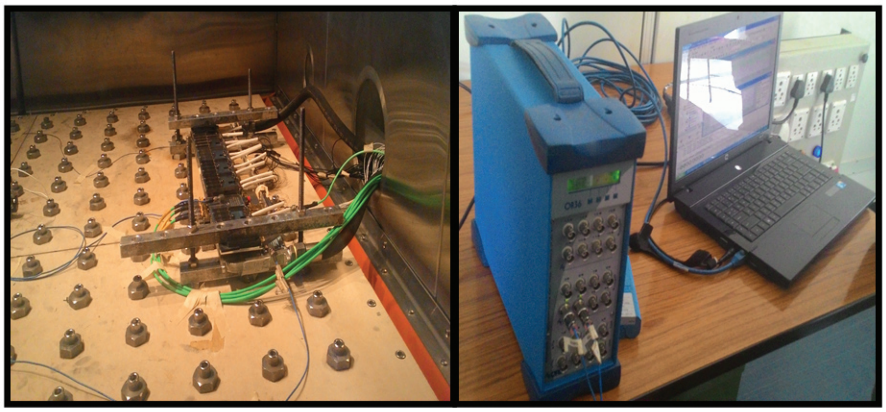


Figure 6. HALT: Vibration test setup using DAQ.

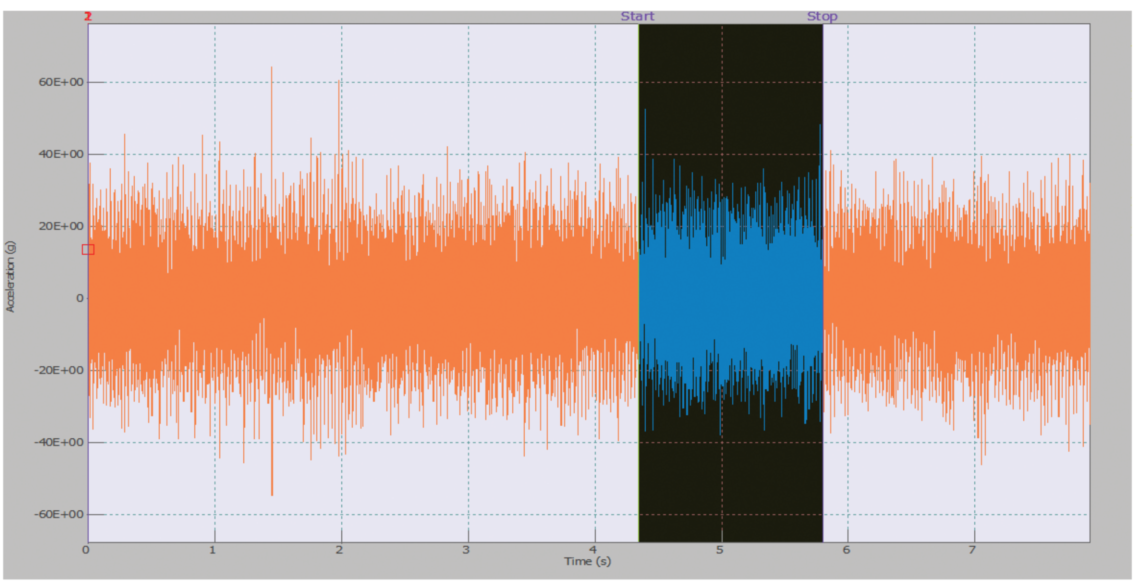


Figure 7. Data acquisition in time domain for frequency bandwidth of 10-10 KHz for 10 grms input stress.

HALT-Dynamic testing as given in Fig. 5. DI for failure is carried out.

7.10 FRACAS: Preventive and Corrective Action

- HALT Vibration test repeated using recommended coating thickness & correct bonding process
- Ensure cross bracket were used inside lid of QTRM cover
- Use proper fixture simulating actual mounting configuration is as shown in Fig. 6.
- HALT test repeated, no failure noticed test completed satisfactorily

7.11 HALT: Data Acquisition During Vibration Step Stress Test

7.11.1 Pre-Recorder Setting for Condition 1

- Frequency Bandwidth = 10-10 KHz
- Sampling Frequency = 25 KHz (Nyquist Criteria)
- Transducer on Channel -1 on QTRMs

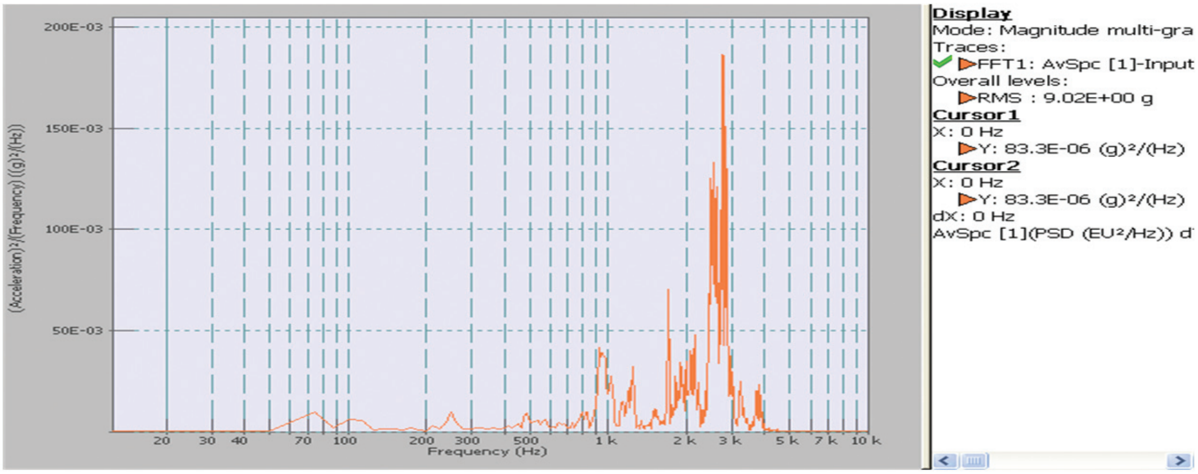
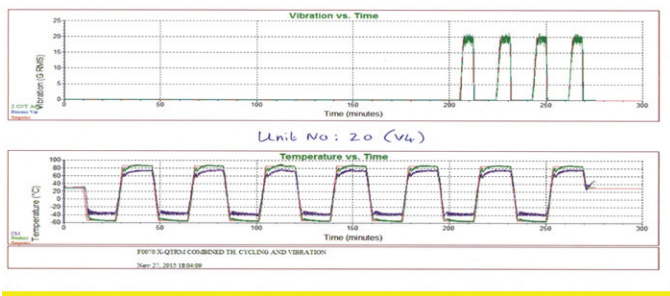


Figure 8. Data acquisition in frequency domain for frequency bandwidth of 10-10KHz for 10 grms input stress.



Note: Combined temperature and vibration test completed successfully, no mechanical or PCB failure noticed

Figure 9. Two combined temperature and vibration test.

- Transducer on Channel -2 on Plank

7.11.2 FFT Setting

- Range = 10 KHz
- No. of Lines = 801
- Resolution = 12.5Hz

7.12 Combined-HALT: Vibration and Temperature

Continue to the accelerated testing an combined stresses of both thermal and dynamic stresses was induced in the QTRMs.

The main objective of the CHALT accelerated testing is to simulate the effect of combined thermal and dynamic stresses on the product and to verify that the combined temperature and vibration environments do not raise the temperature LOL, lower the temperature UOL or decrease the vibration level UOL. This will aid in building reliability of the device / components towards designing the product failure free

8. CONCLUSIONS

The manuscript discussed in detail, how to build reliable and durable QTRMs for airborne fighter class platform comparing the limitation of age old conventional approach of qualification (Which is a time consuming process and doesn't able to simulate the actual field condition) to the new test's methodology that was evolved using AAGT models in the form of HALT and HASS. The outcomes of Accelerated testing approach was used to quickly uncovering the design weakness at much faster rate and is been implemented initially as a pilot project on QTRMs for airborne platforms.

These accelerated models is used to identify the design margins of the product, performance limits, screening, and destructive margins. Accelerated test is carried at initial design phase. The test stresses the product at a significantly higher stress rate than normal operating condition thereby creating demanding scenarios towards forcing the technical design limits and defining the process maturity. This accelerated life testing screening has the following advantages:

- Quickly discover design & process flaws
- Assess and enhance design margins
- Cut back on development costs & time
- Fix design and process issues before production
- Show that your products are reliable

During the manufacturing and production phases, the knowledge of HALT is used to evolve HASS limits to screen the modules using the HASS approach. HASS in general used to quickly identify the latent defects, manufacturing defect in production processes, HASS enable to identify infant mortality/ workmanship issues and also aids in identifying any process improvements and stop delivery of items with latent faults from reaching the market.

- Cut costs and production time
- Improve reliability and quality out of the box
- Lower infant mortality rates

The airborne QTRMs has successfully undergone HALT/ HASS approach using the reliability growth models and completed successfully screening of 12000numbers of QTRMs there by leading towards making a rugged and reliable QTRMs for airborne fire control radar platforms.

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For current study, his responsibilities include: Ensuring the quality and reliability of the LRDE-developed radar system design for all three services. His contribution is to designing the accelerated test models used for conducting the accelerated life testing, finalizing the sample size for ALT, data collection during the test and data assessment.

Dr Nilesh R. Ware is working as Asst. Professor at Defence Institute of Advanced Technology. His areas of interest include: Project management, supply chain management, and quality and reliability methodologies.
For current study, he supervised the finding of this research work.