Electronics Testing Into the 21st Century: Success in Test Is in Strength Capabilities, Not Environmental Specifications

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Development of electronics with increasing shorter market window, faster pace of technological obsolescence, and increasing pace of electronics invasion into almost every appliance and machine manufactured requires that today's electronics be reliable and mature at market introduction. There may not be enough time in the market to improve a poor design. If you ship an unreliable product your customers won't be willing to risk purchasing another electronic product from you and they will probably tell others about your products poor quality. Fortunately, there are extremely efficient and cost effective methods to prevent field failures. These methods are not new but are significantly different from the previous approach and frame of reference of traditional reliability engineering. These methods are derived from HALT (highly accelerated life testing) and HASS (highly accelerated stress screening), The approach is over 25 years old, but have nothing to do with predicting the electronics systems the time to failure and this may be why the industry has such a difficult time adopting or understanding the paradigm shift of HALT and HASS.

The evidence of the effectiveness in reducing warranty returns is overwhelming, yet unpublished, mainly because of its effectiveness and competitive advantage. Would you publish methods that reduced your field failures by a factor of ten, letting all your competitors in on it? Probably not, and that's why the electronics testing community is still reluctant to promote HALT and HASS as the most effective tool for to reliability development and improvement.

HALT and HASS are test philosophies that take a fundamentally different approach from traditional Accelerated Life Testing (ALT). In traditional ALT the test is design to derive a Mean Time to Failure (MTBF). HALT and HASS are not to determine product lifetimes, but instead finding weak elements in the design phase (HALT) or manufacturing latent flaws (HASS) that would result in field failures.

The use and determination of stress levels to find weaknesses is one of the fundamental differences between HALT and HASS and traditional ALT. In HALT the goal is to find the actual, not specified, operation and sometimes destruct limits and then investigating the physics that caused the failure, and determining how those stress margins may be improved to the fundamental limit of the technology (FLT). The FLT is the point at which the product margins cannot be extended without the use of exotic materials or methods. Some components used in electronics have a low FLT compared with typical IC materials. Examples of FLT are the thermal limitations of LCD displays or battery chemistry functional limits. Most of the solid state electronic components in electronic PWBA's are typically heated to solder reflow temperatures which were over 195°C with lead based solder. This reflow temperature has increased in the last few years with the change to lead-free solders. Now components going through reflow have to withstand 230°C without damage for lead-free solder re-flow. Yet, most companies are testing only to temperatures around operational specifications based on the end-use environment. The specifications are typically only -5°C to 40°C for most consumer electronics. Most electronics PWBAs are capable of operation in environments in the range of -40°C to 110°C. Capitalizing on the fact that electronics has a much wider thermal and vibration (mechanical) strength and using the inherent empirical strength and additional stress capability to discover the weaknesses in electronics systems is what leads to rapid product maturity before market introduction. Component and design weak links that limit large operational margins are likely to be the same components and design limits that will have a very significant effect on field operational reliability. By taking the products to the limits through increasing steps of stress, investigating the root cause and understanding the physics of failure, then improving that weak link, companies can make a robust system in the shortest possible time. A robust system will be capable of short effective, intensive, but safe, environmental screens using combined environments while being powered and monitored.

In the Past, Stress Testing was Very Limited

Electronics was, for many years, fragile. Glass tubes and filaments also had inherent wear-out modes that gave the electronics a limited life. Early solid state devices had mechanisms that would also cause failures in time, such as chemical contamination, metallization defects, and packaging defects that resulted in corrosion and de-lamination. A large percentage of these defects were accelerated by high temperature, giving rise to the successful use of "burn-in" to weed out "infant mortality."

Statistical prediction in the 1960's and '70's seemed to have some correlation to field failure rates according to some engineers the author has met that were doing prediction at the time. This was most likely due to the fact that relative to today, a small number of devices, manufacturers, and common limited manufacturing techniques. Today, hundreds of new electronic components are introduced to the market every week, and at the same time hundreds are being taken off the market. It is no longer possible or reasonable to even attempt statistical estimates of reliability based on a summation of components reliability, even if accurate data on current components was available. Deriving an accurate failure rate model is difficult because of the variation in the huge number of applications, component materials, end-use conditions, and life cycle stresses.

Most of today's solid state electronic components do not have wear-out modes that are within most electronics technologically useful life. That being said, early wear out of aluminum electrolytic capacitors have been problematic and have had what appears to be an “early wear out” issues when improperly manufactured or misapplied in a design. This hashas occurred to major companies in the last decade leading to extensive warranty costs. Overall the vast majority of electronic failures is due to defects, either in the design or introduced in manufacturing, or abuse by the customer. The most significant effects on reliability are caused by unplanned errors or events during manufacturing resulting in lowering in the operating strength margins. The root cause can be an engineering change, a change in machine operators, or a change in your vendors manufacturing capabilities. HALT and HASS cannot prevent design and manufacturing errors that cause latent defects, but it is the best method to DETECT the flaw before you ship the product to your customer.

Engineers use time and resources to statistically calculate estimates of reliability with little documented correlation to actual field failure rates. Verification of this fact is easily shown when reliability engineers are challenged to look at warranty failure field returns of their own products, understand the root cause, and determine what traditional statistical probabilistic reliability methods would have prevented those field failures. Rarely if ever is the root cause a “normal wear out” of a solid state electronic component.

The future life cycle stress for any one electronic assembly is unpredictable. The number of points of failure in electronics is vast and the failure mechanisms most times have latent defects failure with multiple stress interactions, making modeling and time to failure estimates very complex. Broad assumptions must be made about life cycle stresses as specific conditions and their distributions are rarely known in detail.

The relation of field stresses and inherent field strength of a product is illustrated in Figure 1. As long as the design strength exceeds the end-use stress no failures occur. Limiting the variation in manufacturing the product should be controlled by using Statistical Process Control (SPC) methods. The variation in life cycle end-use is difficult to limit as the customer environmental conditions are not controlled and can vary widely. Failures occur when the weakest units are subject to the highest stresses as shown in Figure 2.

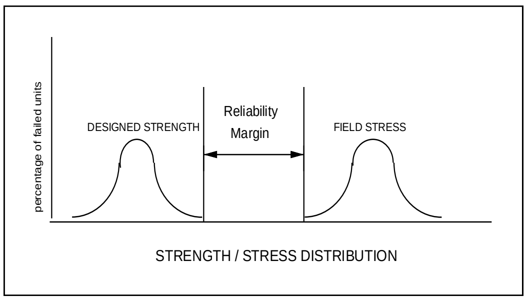
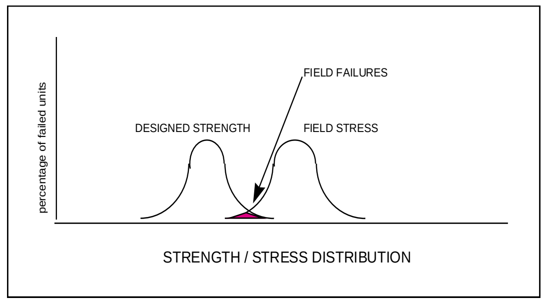


Figure 1



It is important to remember that when a electronic product is manufactured in volume, there is a distribution of its inherent strength around its original designed strength. The end-use environment is even more uncontrolled and has much wider distributions in most cases. No matter how you specify the end-use conditions, your customers will push those limits, possibly unknowingly. By developing a robust design, the product can better survive these extremes. The difference in costs between a robust, well-centered design and one with design weaknesses is usually very small, if any. Changing the orientation of a component, location, or using a more capable component, is very cost effective in the design phase. Some thermal margins on IT equipment has been increased by 30°C by only a change in software/firmware. HALT and HASS can even be very cost effective after the product has been in production for some time.

A Case History of HALT to HASS

An example of the great Return on Investment (ROI) of HALT to HASS would be the case of Advanced Energy Industries (AEI) adopting HALT and HASS over 20 years ago. AEI is a producer of precision power supplies used for thin-film deposition systems. AEI had a product that had been in production 18 months with a fairly consistent 5% annualized field return rate. The current ongoing reliability test was performed at elevated temperature around 32°C in a burn-in room that ran the finished units for 4 days. The product was powered but not monitored for 96 hours.

HALT testing found that the operating limit of the original design that was shipping was only 15°C above the design specification of 35°C. The limit was found to be caused by a 500 volt

100 amp bipolar switch (two per unit). Fortunately a 150 amp switch with the exact same package size could easily be substituted for the 100 amp switch. By replacing the 100 amp switch with a 150 amp switch the operating and destruct limit was moved up to a minimum of 90°C. With the new operating margins, a short HASS process was developed. The HASS process was applied based on the new HALT operational limits. The HASS stress cycle regimen consisted of 3 thermal cycles from -40°C to 75°C with vibration levels up to 25 Grms input. The HASS process duration was one hour for two units. Within six weeks of applying the HASS process the field return rate dropped 90%, that is that the warranty return rate quickly fell from 5% to only 0.5%. Additional savings was realized from reduced inventory because the manufacturing cycle time was also reduce by three days,.

Another good example of how changing only one or two elements can significantly increase an operating margin was found with another AEI product. The whole system had an operating limit of 60°C due to a small +15 vdc auxiliary power supply inside a RF power supply. The limiting component was found to be a small regulating diode located next to a heat sink but not touching it. By bending over the component to make contact with the heat sink, the operation limit was raised by 30°C from 60°C to 90°C. Large margin improvements can be made sometimes by just repositioning a component. This would not have been found if the operating limit had not been discovered through step stress.

For the next 5 years, AEI made this process company confidential. Later, they allowed information on their success and advanced reliability testing methods to be published at the IEEE Workshop on Accelerated Stress Testing in the year 2000 as they realized that few companies understand or use the approach of HALT and HASS and the marketing benefit was greater than the competitive concerns.

The basic paradigm change that must occur for HALT and HASS to be effective is that designers realize that failures above and below specifications are relevant and significantly impact field reliability. The point is to reach the FLT of the design early in the development process.

Discovery and Understanding of the HALT Paradigm

Once the new paradigm is accepted and step stress is used to find the operational and destruct limits, engineers will find that some designs need no changes and very robust from the initial design. A HASS process then can be applied without changing the design. Experience with the HALT method and knowing from experience the stress capability of their designs will lead hardware engineers to benchmark stress limits and use those levels to determine the fundamental limit of their technology. The improvement in field reliability and the low cost of changes to increase stress margins will also become evident.

HALT is not a complicated process. Generally one environmental stress at a time is used to make understanding the physics of the failure mechanism simpler. If time permits, combinations of stresses can be applied in increasing steps. Combined environments can, but the authors experience is that they rarely show a design weakness that would not be found when a single stress is taken to the operational or destruct limit. Combined stresses are an absolute must for an efficient and effective HASS process.

HALT evaluations require only a few units to complete. Three units is a good number of test samples to start with. More units may be needed to see the deviation of a particular operational limit. For instance, a thermal HALT on three samples may show widely distributed operation limits of 56ºC, 88 ºC and 93ºC. The wide deviation may indicate a manufacturing capability issue, which should be understood and reduced if possible. Otherwise the variations may affect reliability if the tail of the strength distribution as it extends into the stress end use conditions. The order of stresses applied should be from least to most destructive to get the most information about each UUT before requiring repair or scrapping it. Typically the order of stress application is cold, hot, and then random multi-axis vibration. If time allows and the failures from single stress HALT are understood, combined stresses may then be used to observe additional detection of weaknesses and to try combined benefits HASS development.

For thermal HALT, each stress step is held long enough for the entire product to reach the set point or within 1°C or 2°C. This is typically 10-15 minutes for most products, but it may be longer if diagnostics need more time to complete before the next thermal step. Temperature is lowered in steps, continuing to the point at which it no longer operates, or fails to operate normally. This is the thermal operational limit. The limiting component should be determined with careful failure analysis. If it is found that the component fails due to a manufacturing defect, the HALT procedure needs to be repeated on a defect free sample. Latent defects can be found during the HALT evaluations, but it is undesired as it masks the true design strength capabilities.

The second part is using high temperature, step stressing in 10°C steps to the operational limit. This is typically, but not always, a destruct limit. Generally most HALT/HASS users consider an upper operating limit of +100 °C to 110°C and lower thermal operational limit of -40°C as a sufficient margin for most electronics and no changes would be necessary. Yet if larger thermal margins are easily realized with small changes, there is a future benefit in creating a more intense and faster HASS process.

Finally, multi-axis vibration is applied in increasing steps of 5 or 10 GRMS. Frequently the operational and destruct limits under vibration are at the same vibration level. As in the thermal HALT, the limiting component should be determined. Vibration failures are usually easier to find than electrical functional issues as vibration failures are more likely to show cracked traces or broken leads. The vibration robustness can be increased many times by changing the component orientation, or adding a fastener, RTV, or tie wrap to adjacent components or chassis structure.

Even if no screen is developed, improving the stress margins using the HALT process will help the product better survive the extremes of manufacturing and end-use variations. Improving operational margins in HALT not only reduce field returns, but HASS can be performed with a wider temperature range, which creates higher thermal differentials and therefore higher thermal-mechanical stresses making defects detectable much faster and, therefore, a shorter and lower cost for screening.

This article is an overview of a few points on the basics of HALT and HASS. There are many more details to starting and continuing a HALT and HASS program. Experienced help with developing HALT and HASS can significantly reduce questions and errors during the “learning curve” and therefore lead to faster adoption. Adoption and use of HALT and HASS is a major commitment of resources for any company, but the ROI in reduced warranty costs, re-design, re-work, and lost sales is tremendous. Developing a robust design using HALT (even if screening cannot be implemented) is an extremely efficient tool for reaching a rapid design maturity and should be a standard evaluation for all new designs. HASS is a process to precipitate and detect defects and shifts in margins that end up being field failures.

It is important to realize that even though the concept of testing to find limits, basing the testing on actual product capabilities and not specifications, and extending those capabilities to the best possible with current technology, is really very simple. The data is out there that clearly demonstrates this is by far the most cost effective and fastest way to develop a robust product. HALT will not find every defect, but from the authors 21 years of HALT experience, it will find greater than 95% that cause field failures. Convincing designers that improving margins beyond what was originally specified is a difficult task for those who are not experienced in this new approach. Once the decrease in warranty failures are demonstrated most companies readily embrace the HALT and HASS processes. It is taking that first step of finding the limits and following through with changes to improve them. Designers and companies who have discovered that failures above specifications are relevant to the field reliability and spend the time and effort to improve the margins will be the most successful at meeting the reliability expectations of customers for the 21st Century.

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