The Changing Paradigm in the Quest for Electronic Reliability

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Electronics were, for many decades, relatively fragile. Glass tubes and filaments had inherent wear-out mechanisms that limited their lifespan. Early solid-state devices had dominant mechanisms, such as chemical contamination, that also caused a significant percentage of failures over time. 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" in the early 1970's. The ability of the electronic assemblies to withstand vibration was limited by the fact that the discrete components had relatively large mass compared to today's small plastic-encapsulated ICs. Given the fragility of tubes and large, discrete components, reliability testing was considered successful if the product met the worst-case end-use environmental specifications for shipping, storage, and operation.

Most work in the 1960's and 70's on improving reliability focused on reliability assessment, estimation, and prediction. Statistical prediction based on component FIT rates was accepted because designs in the 1960's and '70's were made mostly of discrete components, and statistical estimates of the life of a new design showed a reasonable correlation with the actual MTBF. This was most likely because there were relatively few device types, manufacturers, and manufacturing techniques compared to today. Today, hundreds of new electronic components are introduced to the market every week, and hundreds are withdrawn from the market. It is no longer possible or reasonable to estimate reliability statistically by summing component reliabilities. It is impossible to acquire timely and relevant field data due to the variation across the many manufacturing processes, applications, and end-use conditions in today's electronics. All of these factors have a much more significant impact on the reliability of the electronics field than individual component FIT rates.

Today's components do not have wear-out modes that are within the technologically useful life of most electronics. Those working in the electronics reliability field realize that most failures stem from several factors that could not have been known at the time of design or initial production. Almost all latent defects cannot be predicted in a handbook of component failure rates. Therefore, the vast majority, if not all, of electronics failures that occur in normal use are due to defects, either in the design or introduced in manufacturing.

The leaders in reliability are realizing that they can rapidly use up a small fraction of the overall fatigue life of electronics. With increasingly shorter market windows and the rapid spread of electronics into almost every appliance and machine, electronics must be reliable and mature at market introduction. There may not be enough time in the market to improve a poor design. Customers may be unwilling to take another risk by purchasing an electronic product from an unreliable supplier, and they will likely tell others about your product's poor quality.

There are new methods that take a fundamentally different approach to using environmental stress as a tool for quickly identifying unreliable designs and manufacturing processes. These are testing methods that take a fundamentally different approach. The difference is in finding the actual, not-specified operation and destruction margin limits, then driving those margins to the fundamental limit of the technology and basing testing on those limits. Only by finding and knowing the operation and destruction limits through increasing steps of stress, investigating the root cause of those limits, and understanding the physics of failure at those limits, can you make a robust system in the shortest possible time. These methods are called the Highly Accelerated Life Test (HALT) and the Highly Accelerated Stress Screening (HASS).

A robust system will be capable of shorter, more effective, and more intensive yet safe environmental screens using combined environments.

Unplanned events have the most significant impact on reliability during manufacturing. Most failures in electronics are unplanned and, most of the time, undiscovered changes in manufacturing that result in a lower operating margin. The lower operating margin shifts the strength downward, as shown in Figure 2. Usually, multiple factors and changes together cause a shift in the margin. It can be an EC, a change in machine operators, a change in your vendors' manufacturing capabilities, or a combination of those factors that results in latent defects.

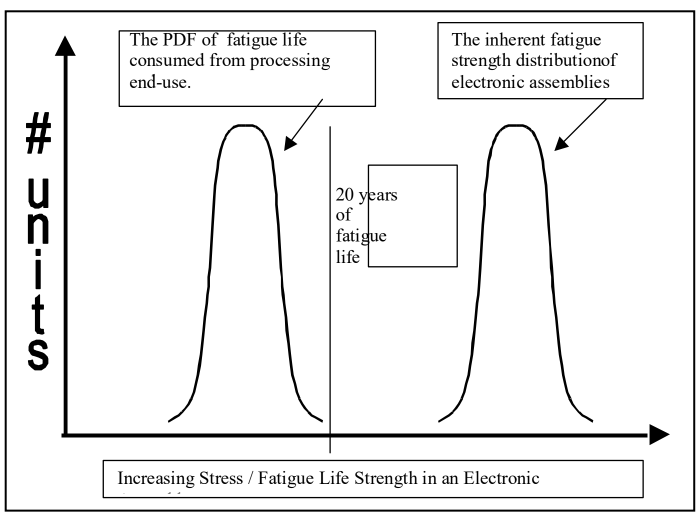
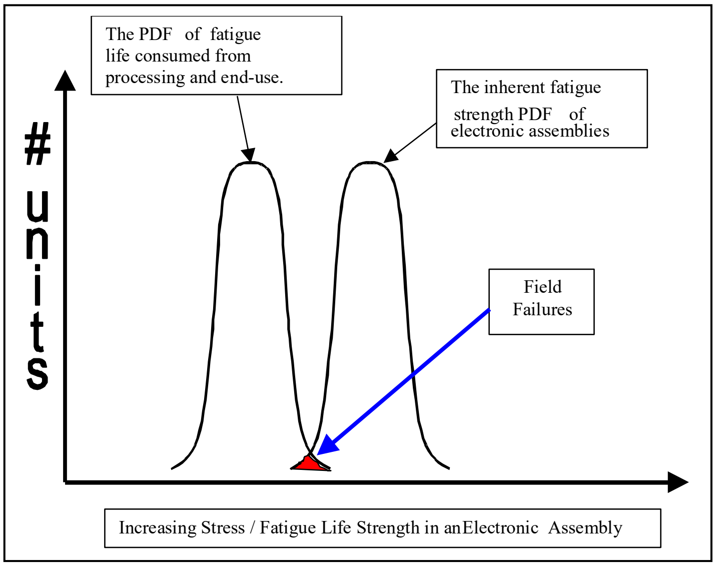


Fig. 1 The Fatigue Life Use vs. Inherent Fatigue Strength Curves



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These events, when combined, result in a very low-strength unit, and they cannot be predicted because no one knew they would occur; they could have been prevented.

The very nature of reliability is that the things you did not think about or know about, at the time, and resources, are trying to calculate estimates of reliability statistically. The future is unpredictable, and in electronics, predictive reliability cannot be achieved with sufficient accuracy to be useful to a designer. Only by discovering the real capabilities and root causes of weak links in the design or manufacturing process, and improving them, can companies achieve significant improvements in reliability.
The relation of field stresses and inherent field strength of a product is illustrated in Fig. 1. Failures occur when the weakest units are subject to the highest stresses, as shown in Fig. 2.

It is important to remember that when an electronic product is manufactured in volume, there is a distribution of its inherent strength around its originally designed strength. The end-use environment is even more uncontrolled and, in most cases, has much wider distributions. No matter how you specify the end-use conditions, your customers will push those limits. By developing a robust design, the product can better survive these extremes. The cost difference between a robust, well-centered design and one with design weaknesses is usually very small. Changing the orientation of a component or its location, or using a more capable component, is very cost-effective in the design phase. It can even be very cost-effective after the product has been in production for some time. An example would be the case of one AcceleRel Engineering client, we'll call Company A. Company A had a product with a 5% annualized field return rate. For reliability testing, they had an elevated-temperature (90 °F) burn-in room. Six months after a one-hour HASS process was applied, the field return rate dropped to 0.5%. Almost always, those who have seen tremendous improvement in their latent defect discovery and the dramatic drop in customer returns don't want to see their competitors learn these methods and then see the same reliability improvement in their competition's product. They have also implemented it across most product lines in production.

The basic paradigm shift that must occur for HALT and HASS to be effective is for designers to recognize that failures both above and below specifications are relevant and significantly impact field reliability. The point is to reach the fundamental limit of the design's technology early in the development process. Please note that a manufacturer's specifications are intended to guarantee performance and operational specs, and their margins vary widely by manufacturer.

Once the new paradigm is accepted and step stress is used to determine the operational and destructive limits, engineers will find that many designs are very robust from the outset and require no changes. They will begin to understand that large gains can be made at a cost-effective price when caught early. Speeding that process up by finding the limits and using those limits for defining the environmental stress that can be applied rapidly, but with little fatigue life cost. Experience will teach hardware engineers that anything less than the design's fundamental limit will impact field reliability, and that improving the design will save a lot of headaches and redesigns down the road.

HALT is not a complicated process. Generally, a single environmental stress is used to simplify the understanding of the physics of the failure mechanism. If time permits, combinations of stresses can be applied in increasing steps. Combined environments rarely exhibit design weaknesses but are the best for HASS. Three to five samples of the units to test are a good number to start with. More units may be needed if a better understanding of the strength distribution of a failing mechanism is necessary. Many get caught up spending a large amount of time on statistical significance rather than understanding the physics of failure and distributions when thousands or millions are manufactured. The order of applied stresses should be from least to most destructive to obtain the most information about each UUT. Typically, this is cold, hot, random multi-axis vibration, and then combining stresses. Using a HASS screen based on the HALT operational temperature range of the product, more effective, higher-stress, and fatigue cycling can be applied so that defects are detectable much faster, resulting in a shorter screening time. Even if no screen is developed, the HALT process will help the product better survive the extremes of manufacturing and end-use variations.

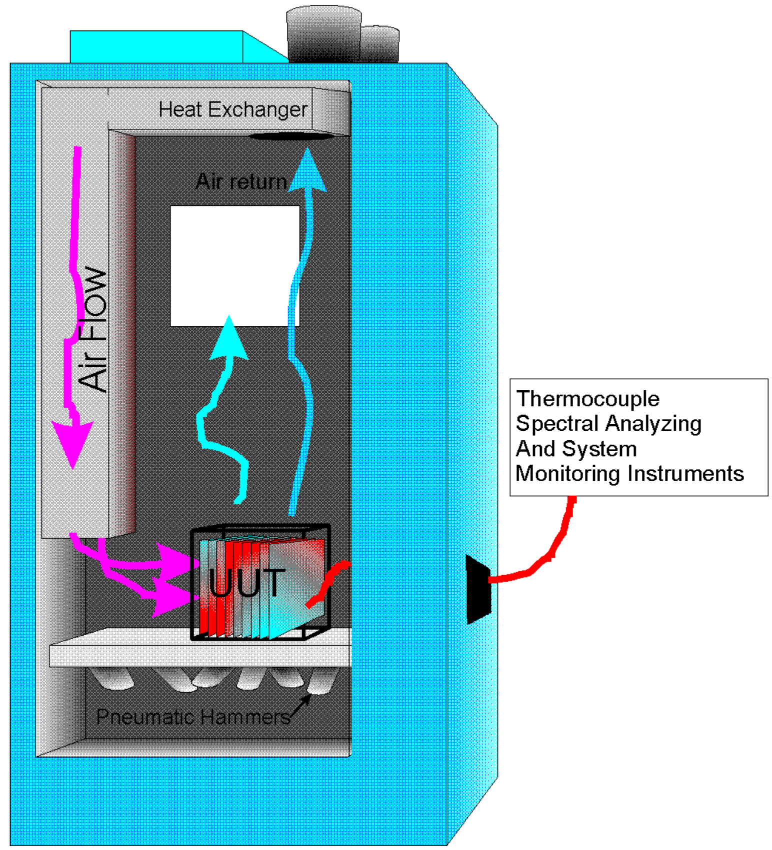

Fig. 3 Typical HALT/HASS chamber

The following is an example of how a very small change that costs very little can be highly effective at improving margins. The UUT had an operating limit of 60 °C, with the small +15 Vdc auxiliary power supply housed within the 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 the component over to make contact with the heatsink, the operating limit was raised by 30ºC to 90ºC. Sometimes, large margin improvements can be made by just repositioning a component. This would not have been found if the operating limit had not been identified through step-stress testing. The product easily met its operating specifications when originally designed. Examples of component layout changes that substantially improve vibration stress margins are shown in Fig. 4 (courtesy of C. Felkins, Storage Technology).

This article is an overview of the basics of HALT and HASS. There are many more details to starting and continuing a HALT and HASS program. It is a major commitment of resources for any company, but the ROI from reduced warranty costs, redesign, rework, and lost sales is tremendous. Developing a robust design using HALT, even if screening cannot be implemented, is an extremely valuable tool for achieving rapid design maturity, and should be a standard evaluation for all new designs. HASS is a process for detecting and resolving defects and margin shifts that lead to field failures.

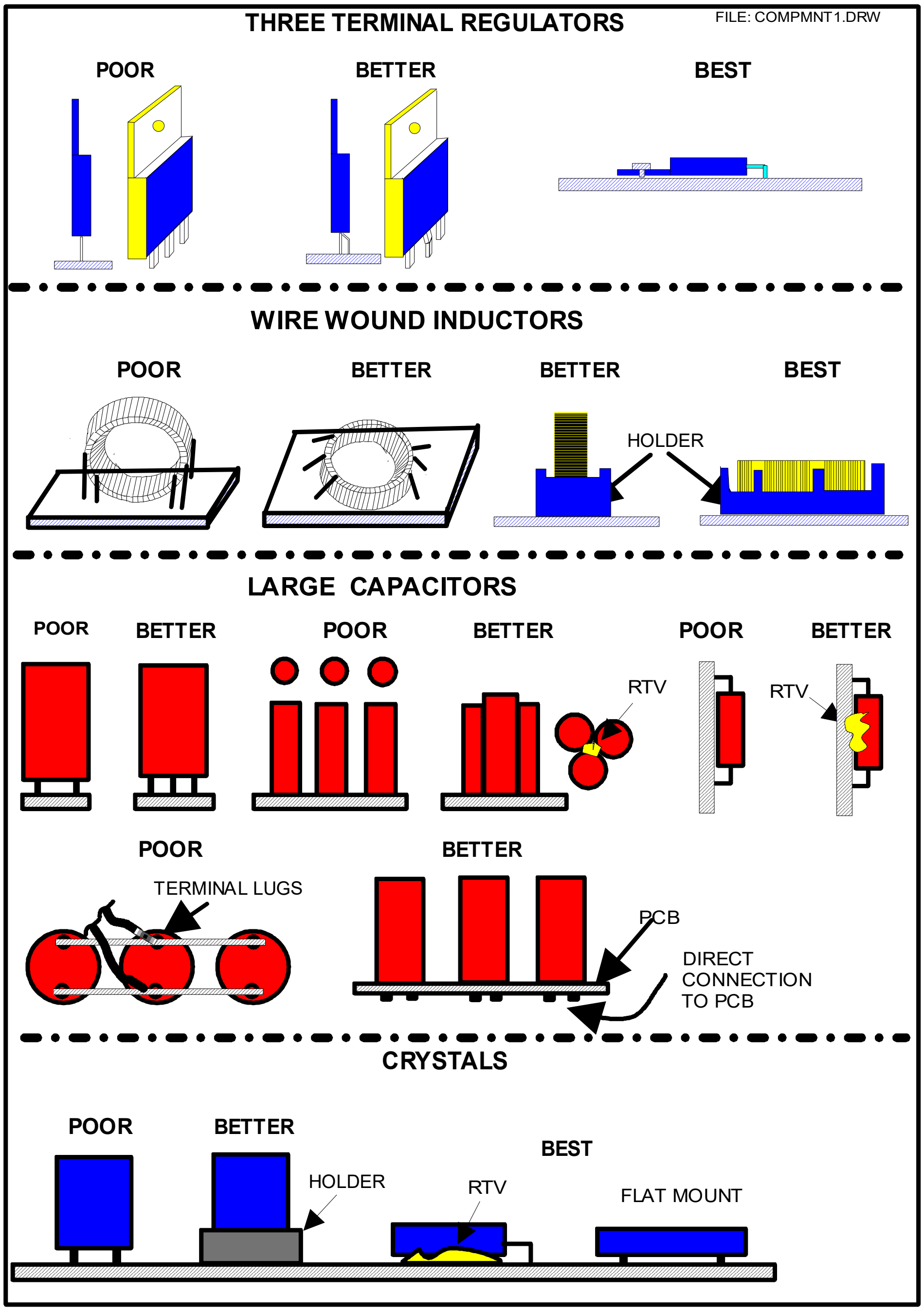

Fig. 4 Component Placement Improvements

Though the concept of testing to find limits is very simple, focusing on material capabilities as the basis for testing and screening is a very difficult paradigm shift for most engineers to make. It finds greater than 99% of the problems that cause field failures. Convincing designers that improving margins beyond what was originally specified is difficult for those not experienced with this new approach. Once the benefits are demonstrated, companies readily embrace the HALT and HASS processes. It is taking that first step of discovering the limits, and sometimes how far they are from the original design specifications, that allows a new understanding of how capable today's electronic components are. That capability can be applied to faster, more effective testing and screening. Designers and companies who have discovered that failures above specifications are relevant to field reliability and who spend the time and effort to improve margins will be the most successful at meeting customers' reliability and cost requirements for the 21st Century.