Reliability Issues Stir Up the ESS Waters

Environmental Stress Screening is a useful tool. But predefining an ESS vibration profile can pose a risk to reliability.

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Environmental Stress Screening (ESS) has proven an effective tool for evaluating the ruggedness of electronics-based systems. ESS exposes products to various environmental conditions to find infant mortalities resulting from part and workmanship defects. But ESS must be used carefully or it can reduce the reliability of the components under test.

Development of a reliable product for harsh military environments has two primary parts. On one hand the product must have the ruggedness capable of surviving the field environment and meeting reliability goals. On the other hand, the production process must be capable of producing a reliable product, free of production defects that can fail prematurely during service life.

The former above is accomplished by the design engineering department. The latter is the job of production engineering and when necessary, assured by post production Environmental Stress Screening.

Problem of Predefining Profiles

ESS is difficult for electronics because electronic systems are complex and rapidly evolving with changing component details—leadwire pitch, component type, solder type (RoHS) and so on. Design methods and ESS must evolve with the product. For military electronics, the ESS vibration profile is often specified by the customer when a product is ordered—sometimes before the product is designed. This ESS specification occasionally allows profile notching for

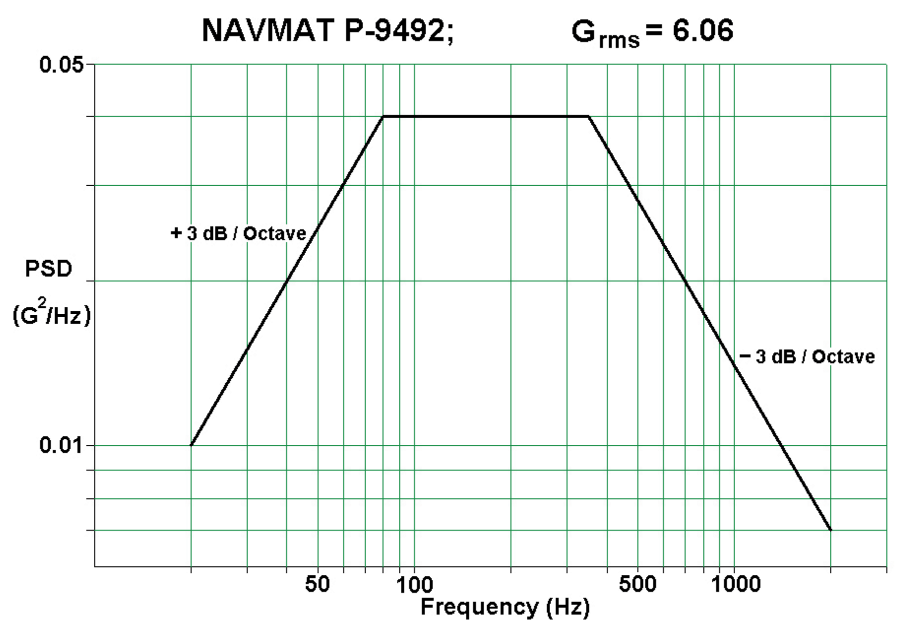

Figure 1

In 1979, the Navy published vibration screening guidelines that have been broadly adopted. Though these guidelines clearly stated that there is a need to customize product screening, many adopted the suggested "starting point" vibration profile directly from this profile. This is the most common predefined ESS profile. Many still use it today, some not knowing how or why it should be modified.

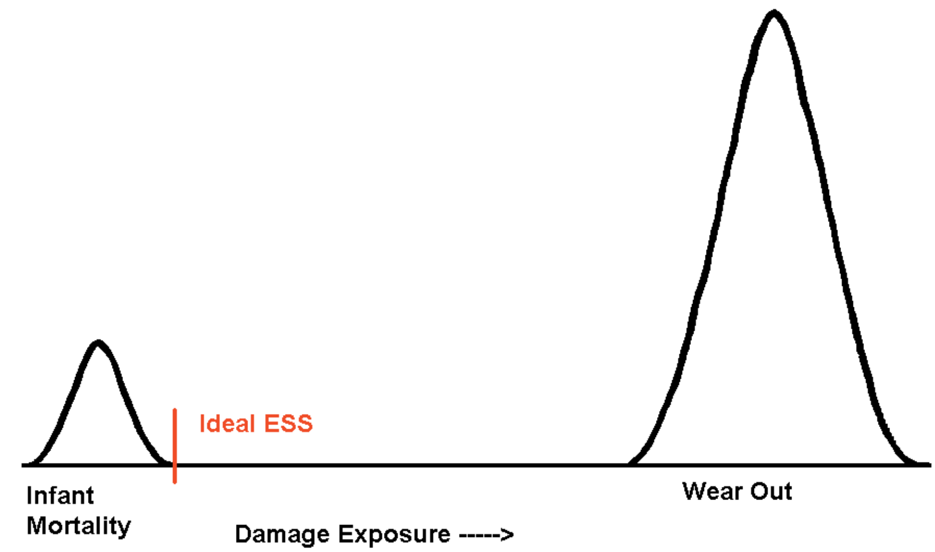

Figure 2

In the bathtub curve, ESS exposes the product to damage that exceeds the infant mortality damage, shown here as "Ideal ESS." This works well with simple products. But military electronics systems are not simple. The product can fail in service life due to thermal cycling or vibration response.

overdriven resonances. The problem is, this method can be adequate for Line Replaceable Units (LRUs) for finding assembly problems such as loose parts or other mechanical components, but it is totally inadequate for circuit card parts.

Effective ESS avoids damaging fragile parts while at the same time adequately exposing areas of risk. The chances that a predefined ESS profile would be effective and non-damaging for circuit card assemblies will not be slim, it will be none. Acceptance of a predefined ESS vibration profile has a high risk of being an acceptance of lowered reliability.

ESS History

In 1979, the Navy published vibration screening guidelines that have been broadly adopted. Though these guidelines clearly stated that there is a need to customize product screening, many adopted the suggested "starting point" vibration profile directly from the document (Figure 1). Many still use it today, some not knowing how or why it should be modified. This is the most common predefined ESS profile.

There are a number of complexities that affect circuit card life. Circuit cards can be very flexible or can be stiffened by frames. Components can significantly affect the local stiffness. Cards can be supported by standoffs, wedge-locks, connectors and frames. In addition, stiffeners, screws, standoffs, board cutouts, or other components can act as "stress risers." Under random vibration, stresses from multiple mode shapes cycle for every part. In addition, electronic products have many physical dimensions and material properties that cannot be tightly controlled, yet are very critical to life.

An example of circuit card evolution is RoHS compliance. The RoHS (Restriction of Hazardous Substances) initiative goes into effect July 1, 2006, and restricts the use of six hazardous materials in electronic equipment, including lead in solder. This will affect COTS parts. Designers must assess the impact of RoHS on their design rules. It will also impact ESS. Of course, this is only one example of the continuous change in circuit card configuration growth.

ESS and Product Life

ESS exposes hardware to environmental loads aimed at preventing infant product failures by creating stress cycles that accumulate fatigue damage. This can precipitate flaws to failure, but every load cycle uses some portion of available product life. Temperature cycling and vibration are commonly used stress screens. Thermal cycling ESS affects all parts but is also highly damaging and requires a long test period. Vibration is excellent for accumulating damage through high cycles in a short time, but there are large differences in damage based on component position. Creating an effective screen requires an understanding of the product at point-of-failure level, matching the needs of the particular product.

For any type of ESS, if the screen is too intense, it uses too much of the product's life and can cause early service life failures. If the screen is too mild or uses the wrong profile or support mode, a flawed product can pass ESS, only to fail early in field use. An effective screen creates enough damage at risk locations to turn flaws into detectable failures.

Methods that depend on field failure experience to improve product or ESS procedures, as in the case of a predefined screen, are not very effective. Shipping a flawed product can affect a product's reliability and the company's reputation. There are a number of terms that correspond to the difficulty of defining an effective stress screen for electronics. These include "each electronic product is unique," "cannot duplicate failures," "no fault identified" and "re-test OK." Such phrases are common because of the statistical complexity of test control, test product variation as well as the scatter to fatigue failures for electronic systems.

Failure Tradeoffs

Tests can generate real failures, but they cannot generate much information about the failures. For most components on modern electronic circuit cards, the most severe stresses under vibration result from card deformations (not inertial loading) defined by mode shapes at natural resonances. Since a test cannot provide any measurements descriptive of the point of failure, testing alone is a difficult approach to gaining knowledge about a product and its life capability under vibration.

The concept of exposing a product to significant damage to eliminate infant mortality is simple. In the bathtub curve, Figure 2, ESS would expose the product to damage that exceeds the infant mortality damage, shown in the figure as "ideal ESS." This works well with simple products. However, circuit cards are not simple. The product can fail in service life due to thermal cycling or vibration response. Product flaws can be found by exposure to vibration and/or thermal cycling.

Vibration is the most efficient means of generating a high number of stress reversals in order to find flaws. But the ESS must not use too much life of the weakest component. Every design has a "weakest" component for a defined support condition and excitation profile. With many of the other components experiencing only a very tiny fraction of damage (relative to the weakest component), will they be adequately damaged to find flaws?

Military and aerospace circuit cards can cost tens and even hundreds of thousands of dollars each. Testing of many parts to gain product knowledge for optimizing screens is often cost-prohibitive. There is a need to get the maximum amount of information available in any test performed.

To create the ideal customized screen, a detailed understanding the product's response to vibration is required. Damage from vibration should be fully understood at the point where failure occurs. Gaining point-of-failure understanding requires detailed analysis. An advantage of including detailed analysis is that information gained from one design is transferable across design configurations. Physics of Failure (PoF) analysis is the application of engineering, science and mathematics for product evaluation at point-of-failure level. PoF analysis can translate test measurements into numerical definition of component life-use (fatigue damage). Tailoring ESS involves modifying controllable parameters to optimize screen efficiency. The two primary variables that are within the control of the screener are fixturing (how the test item is supported), and the vibration profile (including duration).

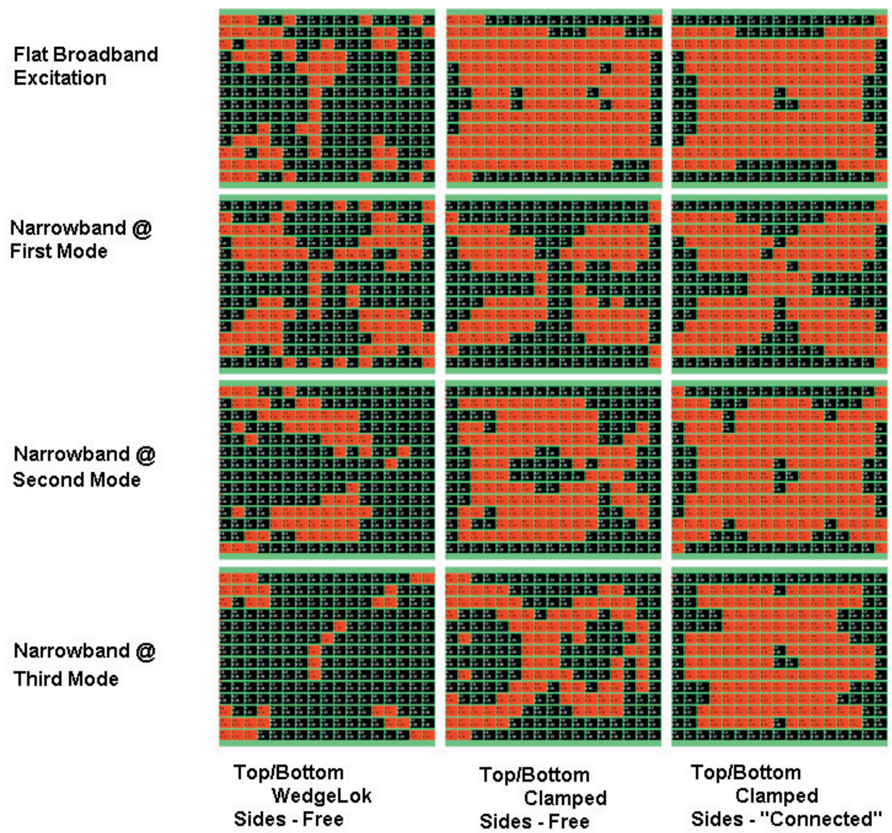

Figure 3

Shown here is the position-dependent damage distribution potential for a single card for three support conditions and four vibration profiles. The red part of the plots shows the areas of high life-use, the black shows lower-used areas.

Physics of Failure (PoF)

PoF detailed analysis of a circuit card demonstrates how a predefined ESS vibration profile will not meet the criteria of being effective and not excessively damaging. ESS process development is far more difficult than design of the product. The designer only needs to develop a product that will meet or exceed the service life goals. Over-design does not imply increased cost, it just requires increased product understanding.

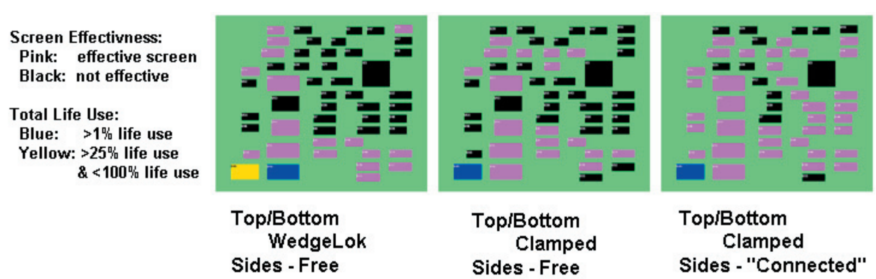

Figure 4

Shown here are the damage plots for an actual design with support conditions matching those from Figure 3.

Fatigue failures are dominated by high stress cycles because there is an exponential relationship between the damage caused by a stress cycle and the amplitude of that stress cycle. This exponential relationship is represented by the high-cycle portion of the fatigue curve of the material at the point of failure.

Highest stresses occur at structural resonance. These resonances can be the vibration of the component itself or of the card assembly. Since local modal circuit card curvature can define the dominant stress in a weak component, component positions are very critical to determining product ruggedness.

The concept of "damage distribution" is important when creating and evaluating vibration screens. The CirVibe software package, a purpose-built PoF program for life-use analysis of circuit cards exposed to vibration, was used in the analysis for the Figures 3 and 4 on vibration fatigue damage.

Position-Dependent Damage

Consider the position-dependent damage distribution potential for a single card for three support conditions and four vibration profiles. As Figure 3 shows, the red part of the plots shows the areas of high life-use. A component in the worst position of the red area could experience 10,000 times as much damage as a component in the worst position of the black area. The plots demonstrate that the life-use in every position is very dependent on both support condition and excitation profile. A vibration screen must expose any risk area to adequate life-use to find flaws without using excessive life of the weakest component. A screen supported by PoF analysis and customized to the product is required for high reliability.

Figure 4 shows damage plots for an actual design with support conditions matching those from Figure 3. These three life plots were determined by analysis of actual components. All plots have the same vibration requirement profile and screen profile. All plots show which components would be effectively screened and those that would not. There is no vibration profile or support condition that will screen everything. A perfect vibration screen is impossible due to the exponential stress/life-use relationship.

Reliability can be reduced by misuse of ESS—a procedure that is intended to enhance reliability. Developing ESS for electronics that is both effective and not excessively damaging requires in-depth product understanding. There is a zero probability that a predefined ESS vibration profile will meet these goals. Since ESS can be a critical part of achieving reliability, ESS procedures should be defined by the developers who understand the product at point-of-failure level. ESS vibration profiles should not be defined by marketing departments or the customer.

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