White Paper

Enhancing MIL-HDBK-217 Reliability Predictions with Physics of Failure Methods

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The Defense Standardization Program Office (DSPO) of the U.S. Department of Defense’s (DoD) has initiated a multi-phase effort to update MIL-HDBK-217 (217), the military’s often imitated and frequently criticized reliability prediction bible for electronics equipment. This document, based on field data fitted empirical models, has not been updated since 1995. The lack of updates led to expectations that its statistically-based empirical approach would be phased out. Especially after science-based Physics of Failure (PoF) [a.k.a. Reliability Physics] research led Gilbert F. Decker, Assistant Secretary of the Army for Research, Development and Acquisition to declare that MIL-HDBK-217 was not to appear in Army RFP acquisition requirements as it had been “shown to be unreliable and its use can lead to erroneous and misleading reliability predictions”[1]. Despite such criticism, MIL-HDBK-217 is now being updated as part of the recent climate within the DoD to re-embrace RAMS methods [2+3]. This paper is a shortened version of a paper presented at RAMS 2010 where the theme was “Transcending Traditional Reliability Approaches” It reviews the reason for the revival and update of MIL-HDBK-217 along with the primary concerns over its shortcomings.

OVERVIEW OF MIL-HDBK-217 - RELIABILITY PREDICTION OF ELECTRONIC EQUIPMENT

The two empirical reliability predictions methods defined in MIL-HDBK-217’s known as “Part Count” and “Part Stress” are used to estimate the average life of electronic equipment in terms of their Mean Time Between Failures (MTBF) which is the inverse of the Failure Rate \( \lambda \) (Lambda). In the “Part Count” method the MTBF value is determined by taking the inverse of the sum of the failure rates (from generic tables) for each component in an electronic device (See Equation 1).

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MTBF = \frac{1}{\lambda_1 + \lambda_2 + \lambda_3 + \ldots + \lambda_n}
\]  

(1)

These basic failure rates can then be scaled to account for the average increase in failure rate caused by operating under harsh environmental conditions such as; ground mobile, naval, airborne, missile, space . . . etc. MIL-HDBK-217 recognizes 14 different generalized generic environment conditions. The “Part Stress” method provides additional generic scaling factors intended to account for the reliability degradation effects of usage stresses such as power, voltage, and temperature. Stress factors may be used earlier in the design process through component derating guidelines, which establish stress rules for components in a particular circuit application.

MIL-HDBK-217 Concerns
There are numerous concerns about the empirical reliability prediction methods defined in MIL-HDBK-217. A summary of the primary criticisms which have been covered thoroughly in other publications [1+2] are:

1) The handbook’s reliability predictions are based solely on constant failure rates which are meant to model only random failure situations.
2) Empirical reliability predictions typically correlate poorly to actual field performance since they do not account for the physics or mechanics of failure
3) The models are based upon industry wide average failure rates that are not vendor, device nor event specific.
4) The MTBF results provide no insight on the starting point growth rate and distribution range of true failure trends.
5) Over emphasis on the Arrhenius model and steady state temperature as the primary factor in electronic component failure while the roles of key stress factors such as: temperature cycling, humidity, vibration and shock have not been individually modeled [3+4+5].
6) Over emphasis on component failures despite RAIC (formerly RAC) data that shows that at least 78% of electronic failures are due to other issues that are not modeled such as: design errors, PCB assembly defects, solder and
wiring interconnect failures, PCB insulation resistance and via failures, software errors. . . etc. [6]
7) The last 217 update was in 1995; new components, technology advancement and quality improvements since then are not covered.

The second part of the revised standard would define Physics of Failure modeling for use during the actual engineering design and development phases of a program. These methods would be used to assess the susceptibility and durability of design alternatives to various failure mechanisms under the intended usage profile and application environment. In this way items that lacked the required durability and reliability required for an application can be screened out early, at low cost during the design phase resulting in more reliable military hardware and systems. Since the 217 Plus approach has been well defined in other publications [7], the rest of this paper will provide an overview to the PoF approach proposed for 217 Rev H.

8) THE MIL-HDBK-217 UPDATE EFFORT

The current effort to update MIL-HDBK-217 into Rev. G known as Phase I is limited to refreshing the data for today’s electronic part technologies. The primary Rev G. goal was to return to a common, consistent method for estimating the inherent reliability of an eventually mature design so that competitive designs could be evaluated by a common process during acquisitions. No new reliability prediction approaches are to be added. There was also a Phase II task to research and develop a proposal for an improved reliability prediction methodology that would be used to create MIL-HDBK-217 (Rev. H). One of the primary Phase II proposals is to add Physics of Failure Reliability methods to the (Rev. H) of 217 which will be discussed further in the rest of this paper.

PHYSICS OF FAILURE BASICS

The Physics of Failure (also known as the Reliability Physics) approach applies analysis early in the design process to predict the reliability and durability of design alternatives in specific applications. PoF focuses on understanding the cause and effect physical processes and mechanisms that cause degradation and failure of materials and components. It is based in the analysis of loads and stresses in an application and evaluating the ability of materials to endure them from a strength and mechanics of material point of view. This approach integrates reliability into the design process via a science-based process for evaluating materials, structures and technologies.

Over the last 25 years, great progress has been made in PoF modeling and the characterization of E/E material properties. By adapting the techniques of mechanical and structural engineering, computerized durability simulations of the E/E devices using deterministic physics and chemistry models are now possible and becoming more practical and cost effective every year. Failure analysis research has led PoF methods to be organized around 3 generic root cause failure categories which are: Errors and Excessive Variation, Wearout Mechanisms and Overstress Mechanisms.

Overstress Failures

Overstress failures such as yield, buckling and electrical surges occur when the stresses of the application rapidly or greatly exceeds the strength or capabilities of a device’s materials. This causes immediate or imminent failures. They occur only under conditions that are beyond the design intent of the device, such as acts of god or war, such as being struck by lightning or submerged in a flood. Overstress is the PoF engineering view of random failures as used in traditional reliability theory. PoF load-stress analysis is used to determine the strength limits of a design for stresses like shock and electrical transients and to assess if they are adequate.

Wearout Failures

Wearout in PoF is defined as stress driven damage accumulation of materials which covers failure mechanisms like fatigue and corrosion. PoF wearout analysis does more than estimate the mean time to wearout failures for an assembly. It identifies the most likely components or features in a device to fail 1st, 2nd, 3rd . . . etc, along with their times to first failure and their related fall out rates afterwards, for various wearout mechanisms. This enables designers to determine which (if any) items are prone to various types of wearout during the intended service life of a new product. The design can then be optimized until susceptibility to wearout risks during the desired service life are designed out.
Errors and Excessive Variation Related Failures

Errors and excessive variation issues comprise the PoF view of the traditional concept of infant mortality. Opportunities for error and variation touch every aspect of design, supply chain and manufacturing processes. These types of failures are the most diverse and challenging category. Since diverse, random, stochastic events are involved, these types of failures can not be modeled or predicted using a deterministic PoF cause and effect approach. However, reliability improvements are still possible when PoF knowledge and lessons learned are used to evaluate and select manufacturing processes that are proven to be capable, ensure robustness and implement error proofing procedures.

INTEGRATING PoF INTO MIL-HDBK-217.

The 217 work group developed a dual approach for integrating PoF overstress and wearout analysis into 217 Rev. H along side improved empirical prediction methods. One proposed PoF section addresses electronic component issues while the second deals with Circuit Card Assembly (CCA) issues. These sections are meant to serve as a guide to the type of PoF models and methods that exist for reliability assessments.

Physics of Failure Methods for Components

The proposed PoF component section focuses on the failure mechanisms and reliability aspects of semiconductor die, microcircuit packaging, interconnects and wearout mechanisms of components such as capacitors. A current key industry concern is the expected reduction in lifetime reliability due to the scaling reduction of IC die features that have reached nanoscale levels of 90, 65 and 45 nanometers (nm) [8]. Models that evaluate IC failure mechanisms such as Time Dependent Dielectric Breakdown, Electromigration, Hot Carrier Injection and Negative Bias Temperature Instability are being considered to address this concern [9].

Physics of Failure Methods for Circuit Card Assemblies

The proposed PoF circuit card assembly section defines four categories of analysis techniques that can be performed with currently available Computer Aided Engineering (CAE) software. A probabilistic mechanics [10] approach is used to account for variation issues. This methodology is aligned with the Analysis, Modeling and Simulations methods recommended in Section 8 of SAE J1211 - Handbook for Robustness Validation of Automotive Electrical/Electronic Modules [11]. The 4 categories are:

1) E/E Performance and Variation Modeling used to evaluate if stable E/E circuit performance objectives are achieved under static and dynamic conditions that include tolerancing and drift concerns.

2) Electromagnetic Compatibility (EMC) and Signal Integrity Analysis to evaluate if a CCA generates or is susceptible to disruptions by Electromagnetic Interference and if the transfer of high frequency signals are stable.

3) Stress Analysis is used to assess the ability of a CCA’s physical packaging to maintain structural and circuit interconnection integrity, maintain a suitable environment for E/E circuits to function reliable and determine if the CCA is susceptible to overstress failures [12].

4) Wearout Durability and Reliability Modeling uses the results of the stress analysis to predict the long-term stress aging/stress endurance, gradual degradation and wearout capabilities of a CCA [17]. Results are provided in terms of time to first failure, the expected failure distribution in an ordered list of 1st, 2nd, 3rd . . . etc. devices, features, mechanisms and sites of mostly likely expected failures.

9) IMPLEMENTATION CONCEPTS

Each of the four groups contains analysis tasks that use similar analytical skills and tools. Combined, these techniques provide a multi-discipline virtual engineering prototyping process for finding design weaknesses, susceptibilities to failure mechanisms and for predicting reliability early in the design when improvements can be implement at low costs. Most of these modeling techniques require specialized modeling skills and experience with CAE software. It is not expected that reliability engineers would personally learn and perform these tasks. However, the definition and recognition of PoF methods as integral, accepted, reliability methods for creating robust and high reliable systems is expected to help connect reliability professional with design engineers and help integrate reliability by design concepts into design activities.

The PoF sections are not intended to mandate that every model has to be applied to every item in every design or that modeling is limited to only the listed models since new models are constantly being developed. Furthermore, the list is not all inclusive since PoF models for every issue do not yet exist. The goal is to identify existing evaluation methods that can be selected as needed during design and development activities to mitigate reliability risks. This way, more reliability growth can occur faster, at lower costs, in a virtual environment during a project’s design phase.
By establishing a roadmap for merging fundamental engineer analysis and reliability methods, a technology infrastructure can be encouraged to continue to grow (perhaps faster) to provide more tools and methods for reliability engineers and product design teams to use in unison.

DfR is already poised to support companies and organization with implement PoF methods to prevent problems in new products or to root cause and resolve reliability issues with existing products as DfR can interpret your electronics ability to survive the intended environment and offer methodologies for meeting the requirements of the end use system application.

REFERENCES

[12] S.A. McKeown, Mechanical Analysis of Electronic Packaging Systems,
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