Zebra Technologies' Enterprise Mobile Computing (EMC) Product Reliability Program

Overview

It is important to make use of a comprehensive reliability program that interacts effectively and systematically throughout the product lifecycle. There are no perfect products. Components, devices, and systems will experience failures; therefore, there is a need to understand why and how failures occur, and minimize and predict the occurrence of such failures.

Zebras Technologies' Enterprise Mobile Computing (EMC) product reliability program comprises a set of activities used to improve a product's inherent reliability prior to its release to market by identifying and addressing areas of weakness in the design. The objectives of the reliability program are to:

- Improve the design of products in a shorter period of time
- Gain a better understanding of how combined environment use cases affect products
- Predict field performance

To achieve high reliability, the inclusive reliability program should begin as early as possible in the product lifecycle—starting from concept and feasibility, moving to design and development, and continuing with the monitoring of the product throughout its lifetime. Reliability goals and requirements need to be clearly established, and appropriate qualitative and quantitative analysis methods implemented to ensure that these requirements are met. [1] [2]

A reliability program can only be performed with an understanding of how a variety of combined stresses impact the performance of a product. By understanding potential failure modes and rates, an effective service plan can be put into place.

Furthermore, everyone within the product team, from designers, test engineers, product managers, and customer support teams, should be involved in establishing the goals and processes.

Reliability Definition

Reliability is defined as "the probability that a component or system will perform a required function for a given period of time when used under stated operating conditions. It is the likelihood of non-failure."

Reliability, therefore, is characterized by four important elements: [3]

- Probability—a value between 0 and 1 (0 and 100 percent).
- Performance—failure definition, which also describes that which is considered to be satisfactory product operation.
- Time—mission time, or the specific time (t) during which the system is working successfully, as designed or to specification. It is used to predict the probability of a product surviving without failure.
- Operating Conditions—the surroundings in which the component or system is operating; including, but not limited to, environmental factors, such as humidity, vibration, shock, temperature, and user working profile; length of shift, and how many shifts per day.

PRODUCT FAILURE RATE

The following figure illustrates the failure rate function for a product over time (bathtub curve):

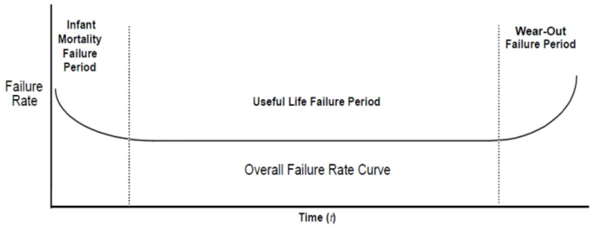

Figure 1: Failure Rate Over Time

The graph displays three regions, including the infant mortality, useful life, and wear-out or fatigue periods:

- Infant Mortality Failure Period—the time during which the failure rate is "high" and a "decreasing failure rate" (DFR), due to manufacturing weaknesses, such as:
  - Poor joints and connections
  - Damaged components
  - Chemical impurities
  - Dirt and contamination
  - Assembly errors
- Useful Life Failure Period—the failure rate remains substantially constant, a constant failure rate (CFR). Although some failures may still arise from manufacturing weaknesses or wear-out, the majority of failures are caused by the operating stresses to which the product is subject in its particular application (for example, temperature, electrical, and environmental stresses) and occur randomly (without any time-dependent pattern).
- Wear-Out Failure Period—the failure rate is "high" and an "increasing failure rate" (IFR), mainly due to prolonged exposure to operating and environmental stresses. Failures may include insulation breakdown, wear or fatigue, corrosion, and oxidation [3] [4].

STRENGTH-STRESS FAILURE MODEL

Failure usually occurs when an item (component, device, unit, etc.) is unable to perform predefined functions. Any system possesses an inherent capacity to withstand the challenges; a failure may occur when challenges (internal and external) surpass the capacity of the system [3] [2].

Figure 1 shows the strength-stress model, which illustrates failures occurring when strength could not withstand stress (fail region). Stress can involve an aggregation of challenges (mechanical, electrical, thermal, etc.) and strength is the capacity of a product/unit to withstand these stresses.

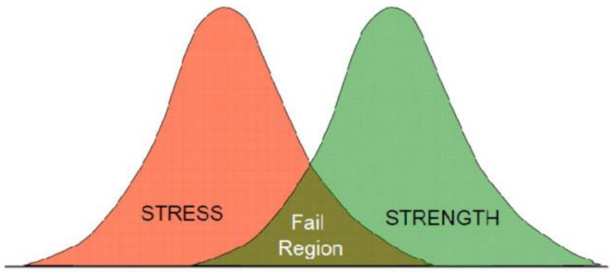

Figure 1: Stress-Strength Model [5]

Reliability Program

A reliability program consists of three main phases: Design for Reliability, Reliability Verification, and Analytical Physics/Physics of Failures.

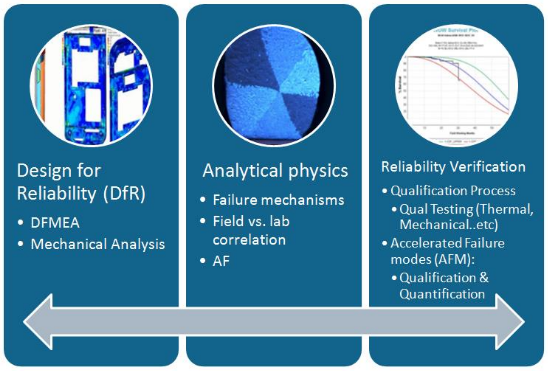

Figure 2: Phases within a Reliability Program

A reliability program begins during the planning and development phases of a product development cycle, continue throughout design and development, and then remain in place as surveillance activities throughout the life of a product.

DESIGN FOR RELIABILITY (DfR)

The Design for Reliability process starts in the concept phase of the product development cycle and continues through product development. The decisions made during the design process greatly affect product reliability. The cost of making changes increases exponentially once the development phase has begun. It is therefore essential to incorporate DfR in the design process [4].

Figure 4 presents an overview of the DfR activities:

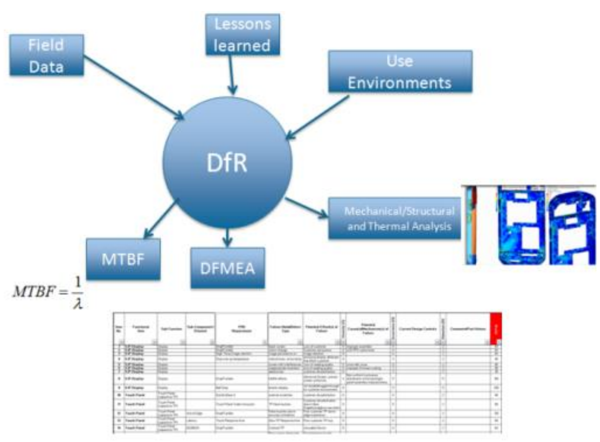

Figure 3: Design for Reliability (DfR) Process

Failure Modes and Effects Analysis (FMEA)

The first major tool within DfR is Failure Modes and Effects Analysis (FMEA). This approach ensures that reliability is integrated within product design. FMEA is used to identify:

- All significant “failure modes” that may occur
- The failure mode effects on a given element
- The severity of such failure
- The probability of the failure occurring

A “failure rate” is assigned to each failure mode. The design team is then able to prioritize issues as they relate to the system and implement improvements within the initial design so as to prevent these failures. [6] [7]

Finite Element Modeling (FEM)

The second methodology within DfR involves simulation, such as Finite Element Modeling (FEM), for mechanical, structural, and thermal analysis.

The FEM simulation approach is used to evaluate the overall structural integrity of a product and its accessories to ensure the product mechanical requirements are met. It provides guidance at the concept and design stages by simulating different use cases involving, but not limited to, the following:

- Drops
- Motion
- Heat
- Impact
- Fatigue (mechanical and thermal)

A particular benefit of this method is that it incorporates the evaluation of the design of structurally critical parts, such as latches, snaps, springs, etc.

Mean Time Between Failures (MTBF) Predictions

The third methodology within DfR utilizes Mean Time Between Failures (MTBF) reliability predictions. These MTBF predictions determine the overall system/subsystem failure rate by summing the failure rates of all components within that system/subsystem.

The failure rate of each individual component is a function of the stresses applied to that component. These stresses always include temperature (both local ambient temperature, as well as temperature rises within the component). Depending on the component type, stresses may also include power dissipation, voltage, current, and operating frequency.

The component failure rate data is used to produce a reliability characteristic in the form of a failure rate, or "MTBF value", for the system/subsystem being analyzed. This data is usually derived from historical data collected from industry-maintained databases (such as MIL-HDBK-217, Telcordia - formerly Bellcore).

The accuracy of reliability predictions depends largely on the availability of detailed design and operating data. These calculations provide "rough" estimates only and should be used for design purposes, and **not** to predict a monthly failure rate or estimate a repair budget, for example.

The following assumptions are used to calculate the predicated failure rate, but do not necessarily represent true use case scenarios:

- All components within the system/subsystem under consideration are connected in series; therefore, if one component fails, the system fails.
- Components' failures are independent from each other.
- The reliability of each component is exponentially distributed (i.e., failure rate is constant). [8]

Reliability Verification Testing

The second activity within the reliability program is Reliability Verification, which normally involves some degree of testing. In general, life tests have two purposes: to verify the product's reliability using both quantitative and qualitative analysis methods.

- A **quantitative** life test is focused on assessing reliability parameters (mainly failure rate), such as Accelerated Life Testing (ALT).
- A **qualitative** life test is used to establish the operational limits of the unit under test, including the behavior at stress limits. Examples of qualitative life testing include Highly Accelerated Life Test (HALT), qualification testing, and engineering testing.

Corrective actions are established after analyzing the test results of both quantitative and qualitative analysis.

TEST PARAMETERS

A general concern of any reliability engineer is whether accelerated tests are relevant to field conditions. The following parameters should be considered when performing any life testing:

- Sample Size—the sample size should produce statistically significant results, while balancing considerations of cost and duration of the test.
- Types of Stress—the types of stresses induced during the test should be representative of life conditions and should only generate failure modes that would be possible in normal field conditions.
- Failure Criteria—the failure criteria should be determined, and is dependent on the specific application.
- Stop End Criteria—the stop end criteria can be either the test duration or the number/percentage of failures.

ACCELERATED RELIABILITY TESTING

Accelerated reliability testing generally simulates field conditions in a very short time period. This can be done by applying stress levels that exceed stresses under normal conditions, and/or accelerating the number of cycles per unit of time. The time-to-failure data obtained under test conditions are then used to extrapolate to use conditions.

Stresses may include high or low temperatures, humidity, voltage, vibration, dust, drop, and combinations of these stresses. Since the main focus is to estimate the product life in service, it is of the utmost importance to choose stresses (and stress levels) that are relevant to service conditions to accelerate failure modes, but to not end up with different failures that would never occur under service conditions.

To be able to accelerate failure modes, however, stress levels should fall outside the product specification limits, but inside the design limits, as shown in Figure 4.

Previous experience with similar products, and design team inputs, should help in determining the appropriate stress levels.

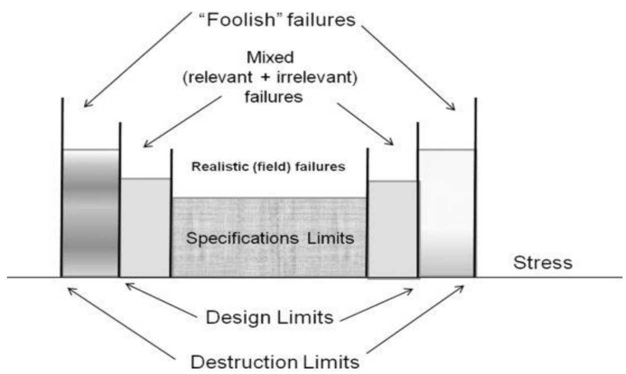

Figure 4: Typical Specification, Design, and Destructive Limits [4]

Accelerated Failure Mode (AFM) Program

Zebra Technologies performs reliability verification testing by means of the Accelerated Failure Mode (AFM) model, which uses a combination of controlled, accelerated stresses driven by customer field environmental working profiles. These accelerated tests include, but are not limited to, stresses, such as:

- Electrical
- Chemical agents
- Humidity and temperatures
- Multiple random drops on all faces, corners, and edges
- Traditional controlled drop, dust ingress, and vibration testing [9]

The following figure shows the effect on the failure rate function, when applying a high, but reasonable, stress to a product.

The failure rate will increase, shortening the product's life by aging the product, due to the combinations of controlled accelerated stresses. [9]

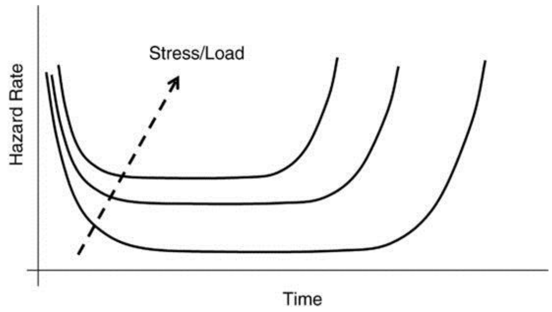

Figure 5: Effects of Accelerated Test on the Bathtub Curve [4]

The curve at the bottom of the plot represents the failure rate over time in the field; the one at the top represents the failure rate under lab conditions, with increased stress/load conditions. To be able to extrapolate the test results back to the field conditions, an Acceleration Factor (AF) needs to be determined.

AFM starts by testing the units at upper and lower temperature extremes, followed by chemical testing, and then the units are exposed to thermal and humidity cycling. Sealing test followed by mechanical testing at room, high and low temperature are then implemented. Typical mechanical stresses include, but not limited to, vibration, drop, tumble, and ball drop.

Failures and Time to Failure (TTF) are recorded throughout the test. TTF is used to generate the reliability function and then calculate the failure rate. It is of the utmost importance to run failure analysis, identify root causes, and implement corrective actions, which is part of the third reliability activity, discussed in the next section.

Damage or failures that occur during AFM are the result of the commutation, and in some cases, combination of the stresses applied rather the result of each individual stress. It is therefore a better representative of field conditions, in which multiple stress factors may exist at any given time.

Statistical tools are used to uncover, identify, and prioritize failures due to design, material, and workmanship within the AFM program. [8]

AFM BENEFITS AND DELIVERABLES

- Development productivity improvement
- Shorter program cycle time
- Lower program cost
- Optimized testing resources
- Improved development effectiveness
- Better field correlation
- Failure mode pareto
- Failure rate prediction
- Reliability/risk assessment
- CAP validation
- Mitigation of program risks
- Product reliability growth
- Statistical analysis of failure modes utilizing competing causes
- Product maturity assessment
- Early detection of field failure modes
- Provides flexible engineering tool for design validation/verification
- Improved product launch success
- Bug-free product
- "True" reliability maturity indication
- Lower warranty and customer TCO costs [9]

Analytical Physics and Failure Analysis

Analytical physics and failure analysis are designed to collect knowledge about a product's "physics of failure." Understanding failure modes and mechanisms, and calculating the acceleration factor (AF) associated with each stress is used to correlate the lab to the field results [10].

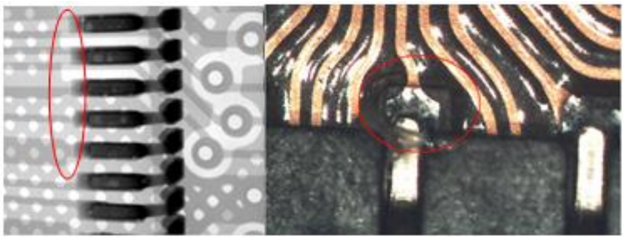

Figure 6: Examples of Failure Analysis to Determine Root Cause

The following table displays various stresses used in AFM, which failure mode and failure mechanism is induced by each stress, and the mathematical model that is typically used for AF calculations.

Stress	Type	Parameter	Model	FM	Impact
Temperature and Humidity Cycles	Thermal	# of Cycles, Frequency, Hot Temperature and Delta T	Modified Coffin-Manson	Fatigue, Delamination, Corrosion, Creep, Deformation	Plastic, IC, Discreet components, PCB, Soldering, Coating, Paint, Printing, Sealing…
Static Temperature and Humidity	Thermal	Temperature, %RH	Peak, Arrhenius	Delamination, Corrosion, IC Typical FMs	Metal, Plastic, IC, Discreet Components, PCB, Adhesive, Rubber, Coating, Paint, Printing…
Vibration	Mechanical	Frequency, Type, Acceleration	Inverse Power	Fatigue, Wear, Loose	Metal, Plastic, Interaction, Interconnection
Shock	Mechanical		Inverse Power	Cracks, "Popup"	Metal, Plastic, Interaction
Drop	Mechanical		Inverse Power	Fatigue, Cracks, Delamination, Popup, Loose	Metal, Plastic, Glass, Interaction, Interconnection
Actuation	Mechanical	Qty, Force, Angle	Linear, Statistical Models	Wear and Tear	Electro-Mechanical Interfaces
Chemical Agents	Chemical	Typical Ambient Environment		Reaction, Diffusion, Peeling	User Interfaces, Coating, Paint, Printing, Plastic, Rubber, Adhesive

FAILURE REPORTING, ANALYSIS, AND CORRECTIVE ACTION SYSTEM (FRACAS)

The Failure Reporting, Analysis, and Corrective Action System (FRACAS) method is used to track, measure, and rank failures in a closed loop process. This method also provides a database of issues for future reference. FRACAS is used to perform statistical calculations that allow the design team to understand in which portion of the failure fate function (or bathtub curve) the product performs, and aim for the "useful life" portion of the distribution.

In order to properly implement corrective actions to a product failure, the true root cause needs to be understood; therefore, fault isolation and failure analysis is required, and adequate corrective actions need to be implemented and monitored.

Examples of Reliability Program in Practice

AFM USED THROUGHOUT DESIGN PHASES OF THE TC75 MOBILE COMPUTER

AFM testing can be performed at various stages of the design—from the vintage design to the engineering stages, right through to mass production. The testing can also be repeated throughout a product's field life (as a surveillance AFM) or to evaluate Design to Value (DtV) changes to a mature product.

The example shown in Figure 7 highlights the improvement to the overall measured failure rate (extrapolated to 12 months of field life) of the Zebra TC75 mobile computer over 5 successive AFMs. This can only be achieved if the identified failures are properly analyzed and the true root causes are implemented. Once these changes are made, the AFM should be re-run to ensure that new, unexpected interactions do not lead to further failures.

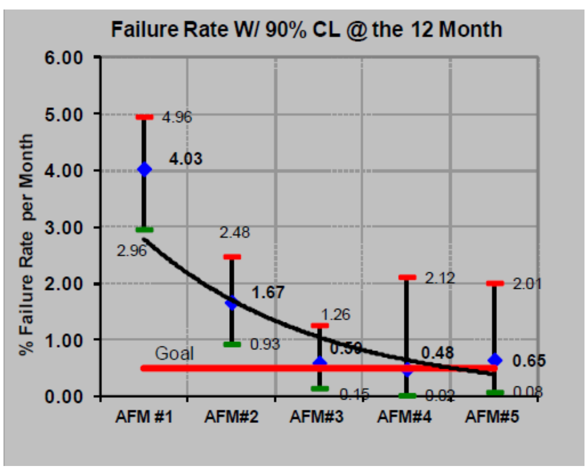

Figure 7: Improvements to Failure Rate Percentage over Successive AFMs

AFM CORRELATION TO FIELD FAILURES OF THE MC95 MOBILE COMPUTER

The AFM process also provides a predictive model in which the 12-month failure rate percentage is compared to the failure experienced once a product has been in the field for 12 months (see Figure 8).

This is valuable data for managing customer expectations, setting up warrantee programs, and developing service contracts.

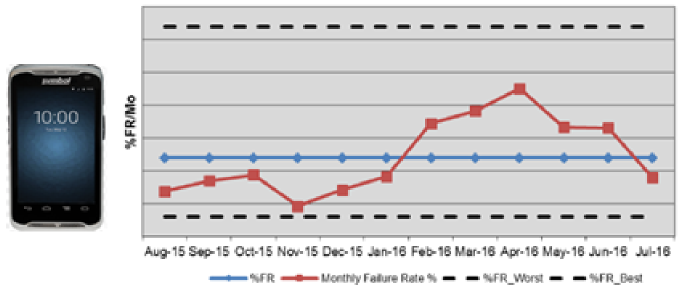

Figure 8: Comparison of AFM to Field Failure Rates

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