Electronics testing: Quality and Reliability

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Electronic Design and Manufacturing consultancy service
- Design-for-X (incl. Manufacturing, Test, Reliability,...)
- Electronic assembly
- RoHS and lead-free soldering implementation

RoHS Service
### 1. A few basic elements

#### Definition of reliability:

Probability that a product will perform its required function under stated conditions for a specific period of time.

- Product reliability is a relative not an absolute property.
- Depends on the product’s design and application.
1. A few basic elements

- Number of failures as a function of time or number of cycles: **The Bathtub Curve**. (Ref: MIL-HDBK-338B)

1. A few basic elements

**Failure function definitions**

- \( f(t) \): probability function for time-to-failure
- \( F(t) \): cumulative distribution function. Probability of failure prior to time \( t \).
- \( R(t) = 1 - F(t) \): Reliability function. Probability of no failure prior to time \( t \).
- \( \lambda(t) = (R(t) - R(t + \Delta t))/\Delta t \): failure rate.
- \( h(t) = f(t)/R(t) \): hazard or instantaneous failure rate. Probability of failure at time \( t \) when no failure took place prior to \( t \).

\[
\lim_{\Delta t \to 0} \lambda(t) = h(t)
\]

- Mean-Time-To-Failure: \( MTTF = \int_0^\infty tf(t)dt = \int_0^\infty R(t)dt \)

\( MTTF = MTBF \) Mean-Time-Between-Failure for repairable systems.

- \( R(t) = \exp\left[-\int_0^t h(t)dt\right] \)
1. A few basic elements

**Distribution functions (Ref: MIL-HDBK-338B)**

<table>
<thead>
<tr>
<th>TYPE OF DISTRIBUTION</th>
<th>PROBABILITY DENSITY FUNCTION, $f(t)$</th>
<th>RELIABILITY FUNCTION, $R(t) = 1 - F(t)$</th>
<th>HAZARD FUNCTION, $h(t) = \frac{F'(t)}{R(t)}$</th>
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</thead>
<tbody>
<tr>
<td><strong>EXPONENTIAL</strong></td>
<td>$f(t) = \lambda e^{-\lambda t}$</td>
<td>$R(t) = e^{-\lambda t}$</td>
<td>$h(t) = \lambda e^{-\lambda t}$</td>
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<tr>
<td><strong>GAMMA</strong></td>
<td>$f(t) = \frac{\alpha^\beta}{\Gamma(\beta)} t^{\alpha-1} e^{-\alpha t}$</td>
<td>$R(t) = \frac{1}{\Gamma(\beta)} \int_0^\infty t^{\alpha-1} e^{-\alpha t} dt$</td>
<td>$h(t) = \frac{\alpha t^{\alpha-1}}{\Gamma(\beta) (\alpha t)^\beta}$</td>
</tr>
<tr>
<td><strong>LOGNORMAL</strong></td>
<td>$f(t) = \frac{1}{\sigma t \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln(t) - \mu}{\sigma}\right)^2}$</td>
<td>$R(t) = \frac{1}{1 - \Phi\left(\frac{\ln(t) - \mu}{\sigma}\right)}$</td>
<td>$h(t) = \frac{F'(t)}{F(t)}$</td>
</tr>
</tbody>
</table>

The selected distribution function is of critical importance for reliability evaluations and predictions!
1. A few basic elements

**Most versatile: Weibull**

$\beta$: shape parameter, $\eta$: characteristic life (often 0 used) = 63.2% failures.

- $\beta < 1$
- $\beta = 1$
- $\beta > 1$

**Physics-of-failure: Stress vs. Cycles to Failure**

- A curve per failure mechanism.
- Required to allow extrapolation towards stress regimes and timeframes outside test range.
- Is actually a failure distribution function $f(N, S)$.

Integrating over all failure mechanisms of the system under the given stress conditions leads to the reliability prediction of the system (in principle).
1. A few basic elements

2. Verification or Qualification testing
   • Goal: Verify or prove a certain level of reliability

3. Production quality testing and improvement
   • Goal: Remove/repair faulty products

4. Testing supporting Design-for-Reliability
   • Goal: Improve intrinsic reliability of the product

Each point on the S-N curve is the result of a cycle-to-failure test.
2. Verification/qualification testing

- Goal: Verify or prove a certain level of reliability

Testing to demonstrate sufficiently low levels of failure during useful life and a sufficiently long lifetime before wearout sets in.

Useful life: *Operational or environmental testing*

*Will the product function under operational conditions according to specifications?*

Relevant names:
- Design Verification Test
- Failure Free Testing
- Environmental testing

Characteristics
- Testing under operational conditions within design limits.
- Relatively short tests (1 day-a few weeks, 1-100 cycles)
- Simulation tests: simulate real life conditions
- No or limited amount of test acceleration.
- No or very small number of failures
2. Verification/qualification testing

Examples:
- Storage and transportation tests
- Operation under different environmental conditions: heat/cold, moisture, vibration, shock, ...

Standards related to operational testing:
- ETS 300 19 series: Environmental Conditions and Environmental testing for Telecommunication Systems
- IEC 60068 series: Environmental testing
- IEC 60721: Classification of environmental conditions
- ANSI

Result:
- Functionality under operational/environmental conditions
- **No failure rate nor life time information is obtained!**

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2. Verification/qualification testing

**Useful life: MTTF/MTBF testing**

Determination of failure rate/MTTF/MTBF in the useful life period of the equipment. Is it acceptable?

Relevant names:
- Reliability testing

Characteristics
- Testing under operational conditions within design limits.
- Relatively long tests in the order of 10-100% of MTTF/MTBF
- A statistical relevant number of failures must occur.
- Shorter test on larger number of samples.
- Simulation tests: simulate real life conditions.
- No or limited amount of test acceleration.
- MTTF/MTBF extraction depends strongly on the selected failure distribution function used for the analysis:
  - Usually: Exponential distribution: random failures/constant failure rate
2. Verification/qualification testing

**Standards related to Reliability testing**
- IEC 60605 series: Equipment Reliability Testing
- IEC 1123: Reliability testing - Compliance test plans for success ratio.
- IEC 61124: Reliability testing – Compliance tests for constant failure rate and constant failure intensity.
- MIL-HDBK-781: Reliability Testing for Engineering Development, Qualification, and Production

**Results**
- MTTF/MTBF or other distribution function parameters estimate. Highly dependent on choice of distribution function.

**Validity of constant failure rate assumption!?**
- **No physics, only statistics!**
- No lifetime information regarding wear out.

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**2. Verification/qualification testing**

**Wearout: Life time testing**

Does the product has a sufficiently long useful life before wearout starts?

**Relevant names:**
- Life time testing
- Accelerated testing
- Reliability testing
- Fatigue testing

**Characteristics**
- Problematic for systems with long lifetimes: require accelerated tests. In general not feasible at system level.
- Systems: long (nearly) failure free testing under operational or mildly stressed conditions.
- Parts level: statistical meaningful number of failures to determine failure distribution.
2. Verification/qualification testing

Standards:
- System level: Special cases of reliability testing using non-exponential distribution functions.
- Part level: see standards for Physics-of-Failure testing like IPC-9701.

Results:
- If sufficient failures are obtained during tests failure distribution parameters can be derived.
- If accelerated tests are used, acceleration factors must be known to determine "real life" failure distribution. Issues:
  - knowledge of acceleration factor?
  - does the failure distribution remain unaffected by the acceleration except for the acceleration factor?
  - no other failure mechanisms introduced at accelerated test?
- Failure free tests give very little information about lifetime.

3. Production quality testing and improvement

- Goal: Remove/repair faulty products

Testing to minimize "dead on arrival" (Time =0) and early failure rate.
3. Production quality testing and improvement

**Production testing: Quality testing**

Assembly testing:
- Inspection (human, automatic, optical, X-ray,...)
- Structural test (flying probe, ICT, Boundary scan,...)
- Functional test

Characteristics
- Fast, go-no go testing plus trouble-shooting & repair
- Factory environment
- Product based test strategy

Results
- Production quality and yield quantification.
- Products that pass the tests. Quality of outgoing products dependent on test coverage of production test.
- Minimisation of numbers of “dead-on-arrival” products

**Product screening: stress testing**

Goal: To transform quality related latent failures that cause early failures into patent failures that can be detected and removed/repaired.

Method:
- Apply certain stress level(s)
- Should not damage good products
- Impact on lifetime of good products should be acceptable

Types of screening tests:
- Burn-in
- Environmental Stress Screening (ESS)
- Highly Accelerated Stress Screening (HASS)
- Highly Accelerated Stress Auditing (HASA)

Ref: IEC 61163-1
4. Tests supporting Design-for-Reliability

Goal:
- To improve the reliability of the product by design.
- Gathering knowledge about potential failure modes.

Characteristics:
- Accelerated tests
- Test to failure
- No qualification or demonstration testing

1. Parts qualification testing
2. Highly Accelerated life Testing
3. Failure mode based accelerated testing

4. Tests supporting Design-for-Reliability

1. Parts qualification testing
   - Testing of parts to fulfill the quality and reliability requirements of the electronic assembly
   - To avoid specific failure modes.

Examples
- Component quality and reliability:
  - ex. Moisture sensitivity: J-STD-20C
- Sn-Whisker propensity: JESD22a121/JESD201
- Solder material induced corrosion and SIR: J-STD-004A, GR-78-CORE,...
- PCB delamination, decomposition, via-cracking,...
- Solderability
- Etc., etc.
4. Tests supporting Design-for-Reliability

2. **HALT: Highly Accelerated Life Test**
   - **Origin:** Hobbs Engineering (Gregg Hobbs)
   - **Principle:**
     - Subject product to ever increasing stress levels until failure occurs.
     - Analyse failure
     - Adapt design to avoid the failure
     - Repeat until all failure modes are removed that do not belong to a “Fundamental limit of Technology”. Ex.: melting of plastic.
     - Testing beyond specification until destruction!

Basic idea:
- High failure acceleration to get results fast

![Diagram showing HALT point and Operating point with NT << N₁]
4. Tests supporting Design-for-Reliability

Benefits
- Fast availability of results.
- Needs only a limited number of product samples.
- Improves robustness of product.
- Knowledge of product capabilities outside design specification range.
- Identification of destruct limits mandatory to establish a HASS/HASA screening.

But... it is a controversial technique because:
- Failure modes irrelevant to operational conditions may be induced...
- ... which may lead to over-designing.
- Relevant failure modes to operation may NOT occur in HALT testing especially for electronics. Examples: Solder joint fatigue, Sn-whisker, corrosion,...
- Highly Accelerated Life Test is a misleading name. HALT cannot predict lifetime because acceleration factors at system level are not known. HALT is NOT a Life Time test!
- HALT = High Stress Test of which the benefits and relevancy must be critically evaluated.
4. Tests supporting Design-for-Reliability

3. Failure mode based accelerated testing.

Physics-of-Failure principle:
- Define relevant failure mode(s)
- Establish S-N curve for each relevant mode:
  - Experiments
  - Physical modelling
  - (Finite Element) simulation
  - Statistics
- Define accelerated test(s).
- Establish acceleration factor(s).
- Perform accelerated tests.
- Establish test failure distribution and predict operational failure distribution using the acceleration factors and the mission profile of the product.

4. Tests supporting Design-for-Reliability

Characteristics, benefits and limitations:
- Wearout oriented: physics not statistics.
- The only way to predict long term wearout lifetime.
- Testing is in general done on specially designed test samples, not on the actual product.
- It is input for the design process. Can be established independent from design cycle. Time-to-market!
- Requires profound understanding of technologies used in the product and the wearout physics involved.
- Limitation:
  Establishing the S-N curves and acceleration factors is a tedious, time-consuming and expensive job with a lot of pitfalls. Therefore, for many relevant failure mechanisms S-N or acceleration factor information is not available. Subject of scientific research.
- For the latter: reliability risk management as part of DfReliability.
5. Examples of electronics failure mechanisms

- Solder joint fatigue caused by CTE mismatch and thermal cycling of product in operation.

Thermal cycling test requirements:
- Heat/cool rate limited
- Allow for minimal dwell times at extreme temperatures: time is essential.
- Materials set limits to temperature extremes

- Surface Insulation Resistance failure: voltage, moisture, ionic contamination lead to conductive path on the PCB surface.

Testing characteristics:
- Storage
- Humidity and temperature (not necessarily the higher the better)
- Voltage bias
5. Examples of electronics failure mechanisms

- Conductive Anodic Filament (CAF) growth in PCB along the glass-fibre

  Testing characteristics: similar to SIR testing


  Testing characteristics:
  - Long time storage: 1000h
  - Temperature: 125°C
5. Examples of electronics failure mechanisms

- Sn-whisker growth on (nearly) pure Sn coatings: compressive stress driven

  Matte Tin Plated 28 pin SOIC Stored at Ambient for 3 years

  Testing characteristics:
  - Compressive stress introduction
  - Thermal cycling and storage (long duration: months!)
  - Too high/too low temperature: no whiskering!
  - Maximum whisker growth rate at 30-60°C

And there are many more:
- Hot carrier degradation in Si components
- Electro-migration in conductors
- Dielectric breakdown, degradation
- PCB delamination
- PCB via cracking
- Pop-coring of plastic packages
- Corrosion
- Solder lead interface failures
- Brittle fracture of solder joint
- High cycle fatigue of solder joints
- ...

- Knowledge of Physics-of-Failure forms the basis of a reliable (electronic) product.
- Testing should be based on this knowledge.
- “Black Box” testing of the product only tells you that the product passes the test (or not).
Thank you for your attention.

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