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**

PCB MANUFACTURING
& PCB ASSEMBLAGE

8 SEPTEMBER & 5 OKTOBER, 2006
EXTRA PCB MANUFACTURING SESSIE: 20 OKTOBER 2006

Georganiseerd door IMEC's Microelectronics Training Center (MTC).

Deze training kadert in de Technologische Dienstverlening ELIAS en het MINT netwerk, beiden gesteund door het IWT.

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Met steun van:

Electronics testing: Quality and Reliability Content

1. A few basic elements
2. Verification & qualification testing
3. Production quality testing and improvement
4. Testing supporting Design-for-Reliability
5. Examples of failure mechanisms in Electronics

1. A few basic elements

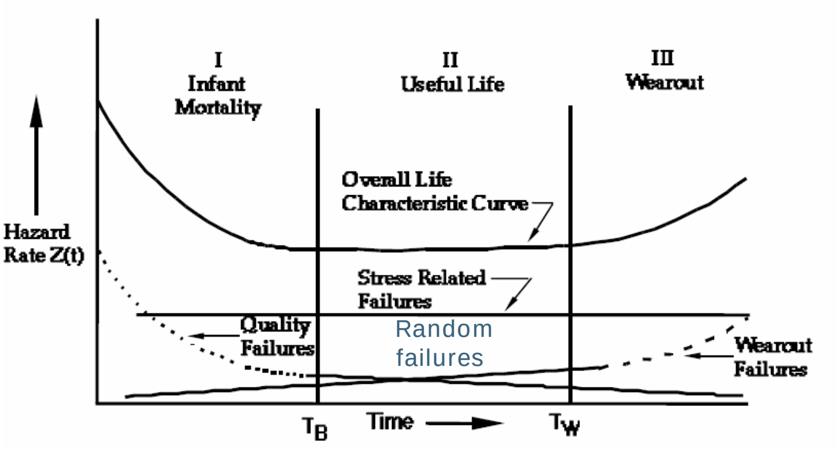
Definition of reliability:

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

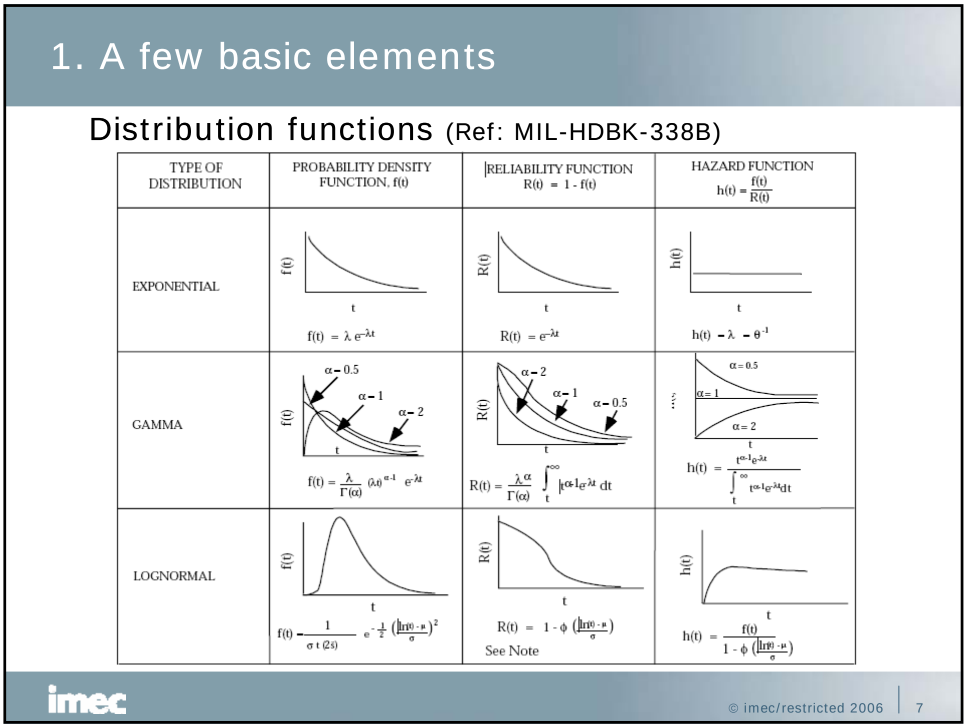
Failure function definitions

- f(t): probability function for time-to-failure
- F(t): cumulative distribution function. Probability of failure prior to time t.

$$F(t) = \int_{-\infty}^{t} f(t)dt$$

- R(t)=1-F(t): Reliability function. Probability of no failure prior to time t.
- λ(t)=(R(t)-R(t+Δt))/ΔtR(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. $h(t) = \lim_{\Delta t \to 0} \lambda(t)$
- Mean-Time-To-Failure: $MTTF = \int_0^\infty tf(t)dt = \int_0^\infty R(t)dt$

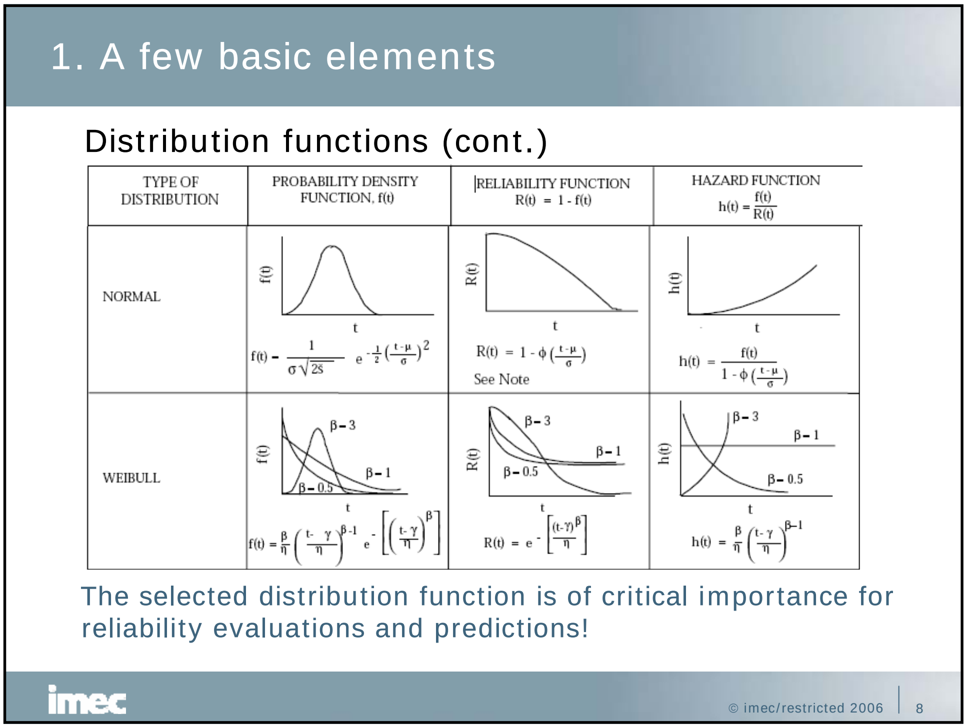
  MTTF=MTBF Mean-Time-Between-Failure for repairable systems.
- $R(t) = \exp\left[-\int_0^t h(t)dt\right]$



1. A few basic elements

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

TYPE OF DISTRIBUTION	PROBABILITY DENSITY FUNCTION, f(t)	RELIABILITY FUNCTION $R(t) = 1 - f(t)$	HAZARD FUNCTION $h(t) = \frac{f(t)}{R(t)}$
EXPONENTIAL	$f(t) = \lambda e^{-\lambda t}$	$R(t) = e^{-\lambda t}$	$h(t) - \lambda - \theta^{-1}$
GAMMA	$f(t) = \frac{\lambda}{\Gamma(\alpha)} (\lambda t)^{\alpha-1} e^{-\lambda t}$	$R(t) = \frac{\lambda^{\alpha}}{\Gamma(\alpha)} \int_{t}^{\infty} t^{\alpha-1} e^{-\lambda t}\, dt$	$h(t) = \frac{t^{\alpha-1} e^{-\lambda t}}{\int_{t}^{\infty} t^{\alpha-1} e^{-\lambda t} dt}$
LOGNORMAL	$f(t) - \frac{1}{\sigma t (2\check{s})} e^{-\frac{1}{2}\left(\frac{\ln(t) - \mu}{\sigma}\right)^2}$	$R(t) = 1 - \phi\left(\frac{\ln(t) - \mu}{\sigma}\right)$ See Note	$h(t) = \frac{f(t)}{1 - \phi\left(\frac{\ln(t) - \mu}{\sigma}\right)}$

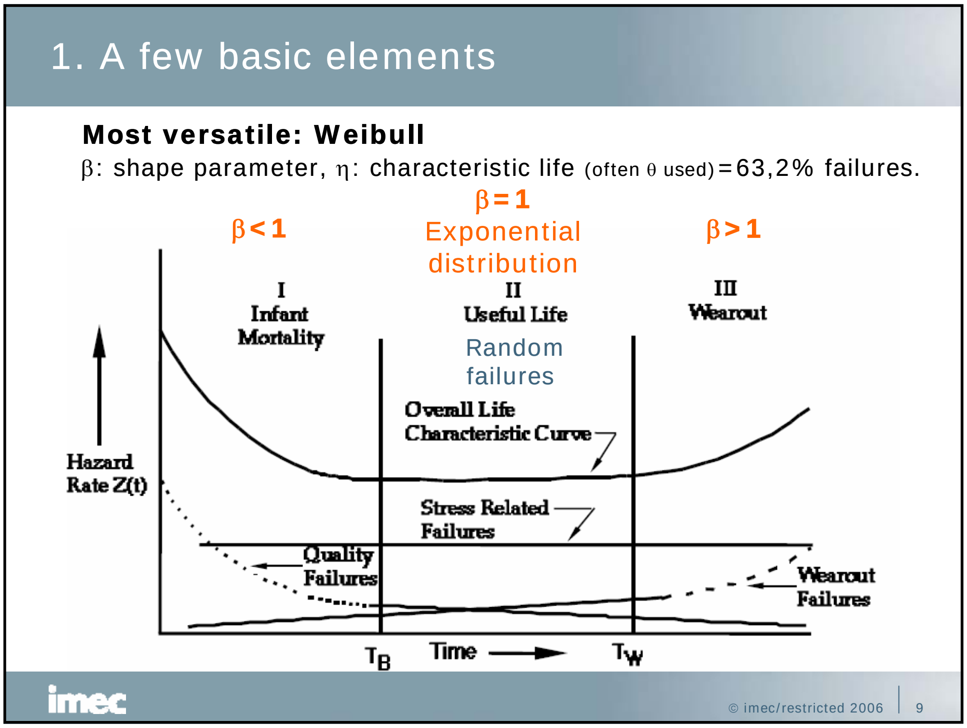


1. A few basic elements

Distribution functions (cont.)

TYPE OF DISTRIBUTION	PROBABILITY DENSITY FUNCTION, f(t)	RELIABILITY FUNCTION $R(t) = 1 - f(t)$	HAZARD FUNCTION $h(t) = \frac{f(t)}{R(t)}$
NORMAL	$f(t) - \frac{1}{\sigma\sqrt{2\check{s}}} e^{-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2}$	$R(t) = 1 - \phi\left(\frac{t-\mu}{\sigma}\right)$ See Note	$h(t) = \frac{f(t)}{1 - \phi\left(\frac{t-\mu}{\sigma}\right)}$
WEIBULL	$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left[\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right]}$	$R(t) = e^{-\left[\frac{(t-\gamma)^{\beta}}{\eta}\right]}$	$h(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}$

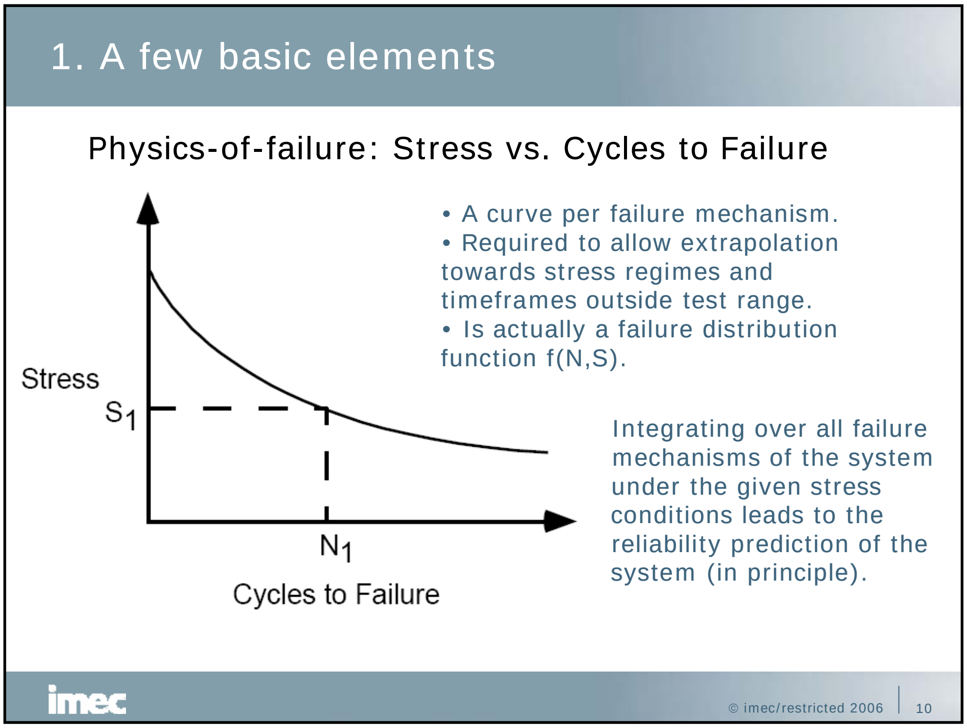
The selected distribution function is of critical importance for reliability evaluations and predictions!



1. A few basic elements

Most versatile: Weibull

β: shape parameter, η: characteristic life (often θ used) = 63,2% failures.



1. A few basic elements

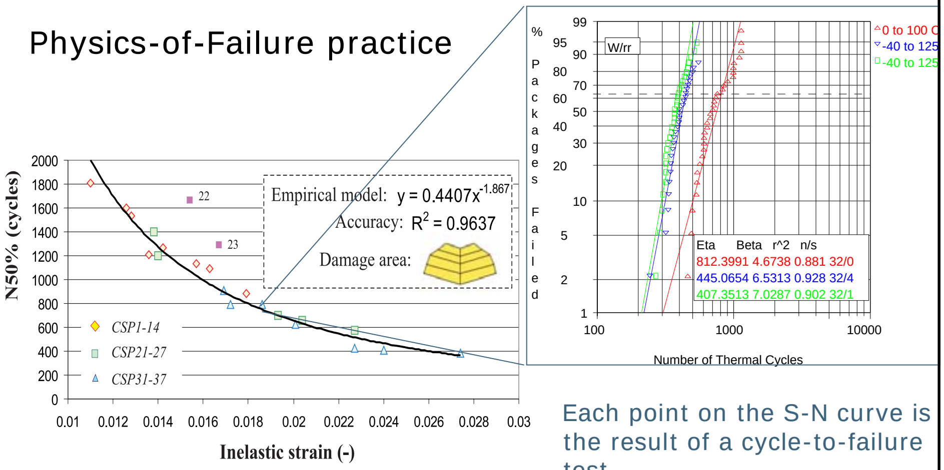
Physics-of-failure: Stress vs. Cycles to Failure

- 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

Physics-of-Failure practice



Each point on the S-N curve is the result of a cycle-to-failure test.

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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

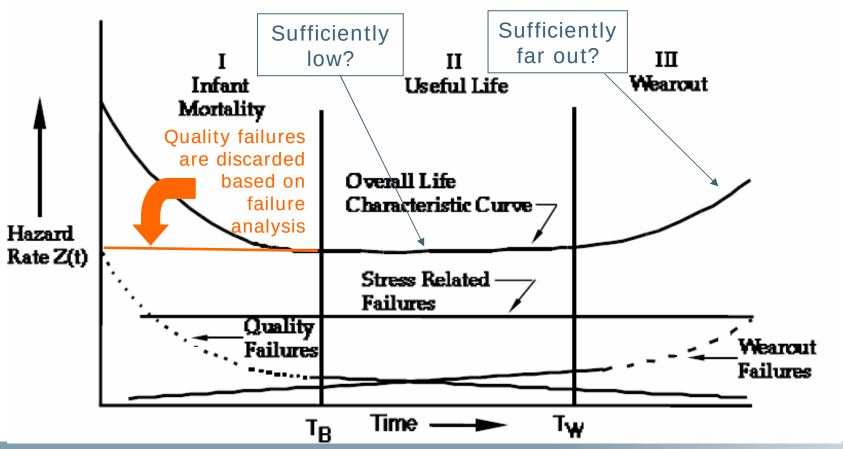
4. Testing supporting Design-for-Reliability

- Goal: Improve intrinsic reliability of the product

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.



Sufficiently low?

Sufficiently far out?

Quality failures are discarded based on failure analysis

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2. Verification/qualification testing

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!**

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: Exponentional 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.

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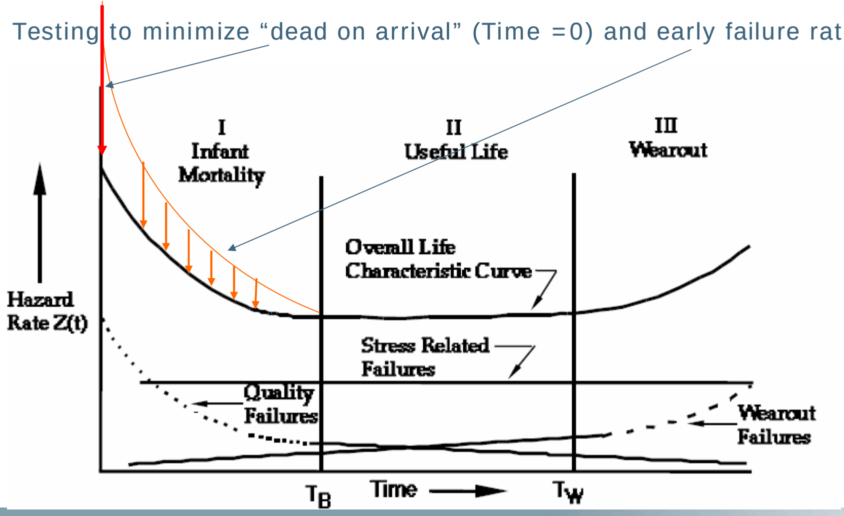
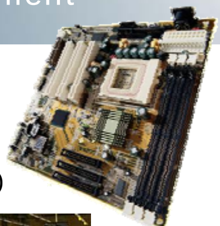
3. Production quality testing and improvement

- 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

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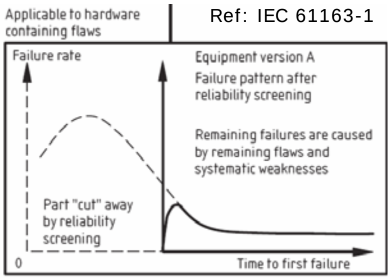
3. Production quality testing and improvement

Product screening: ***stress testing***

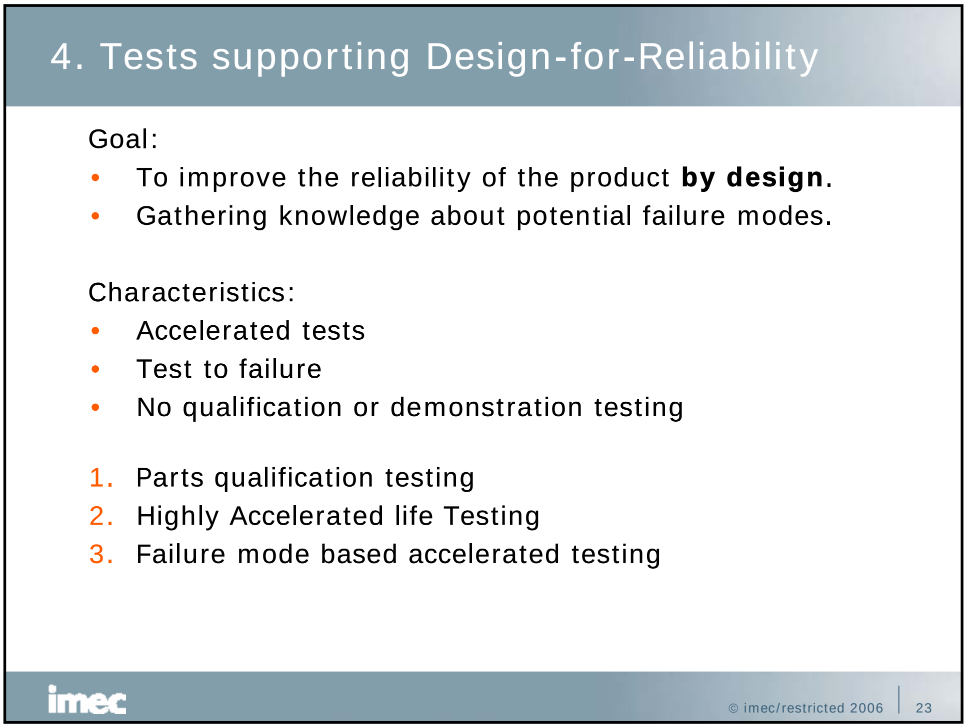
Goal: To transform quality related latent failures that cause early failures into patent failures that can be detected and removed/repaired.

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



Ref: IEC 61163-1

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



4. Tests supporting Design-for-Reliability

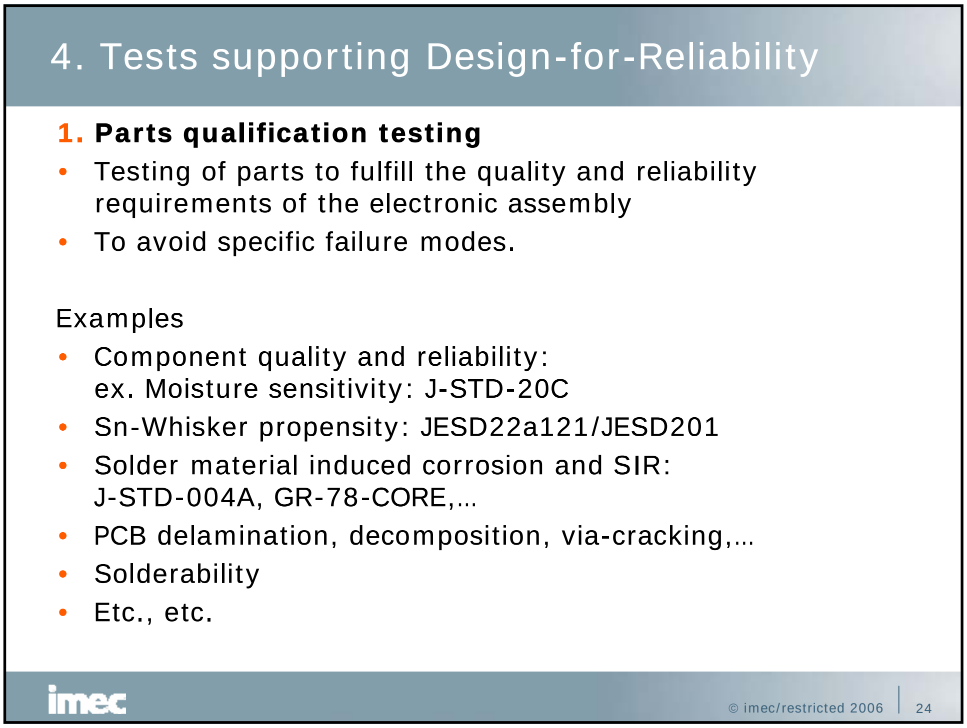
Goal:

- 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.

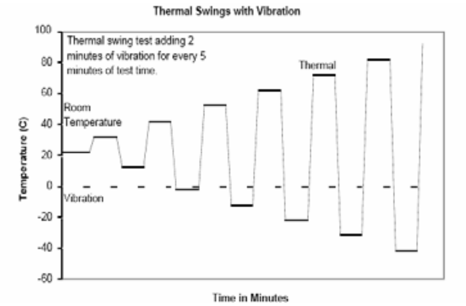
4. Tests supporting Design-for-Reliability

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!

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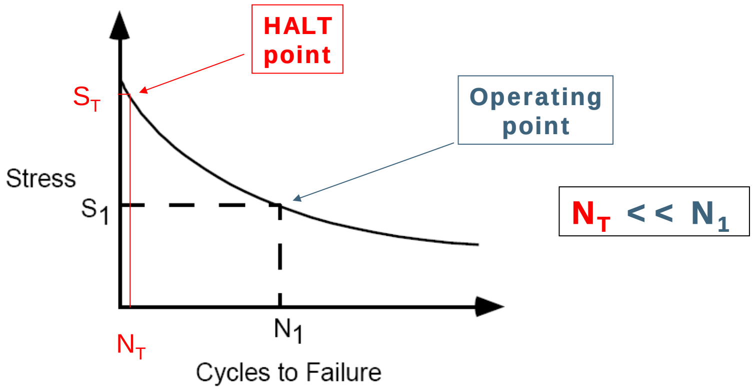
4. Tests supporting Design-for-Reliability

Basic idea:

- High failure acceleration to get results fast



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.

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4. Tests supporting Design-for-Reliability

But… it is a controversial technique because:

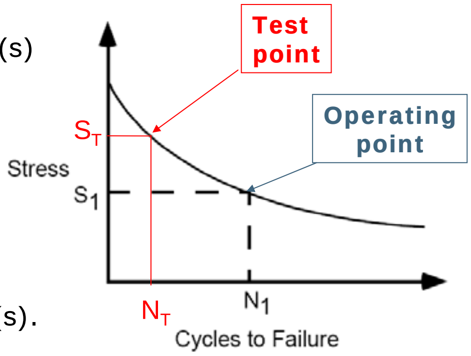
- Failure modes irrelevant to operational conditions may be induced…
- … which may lead to over-designing.
- Relevant failure modes to operation may NOT occur in HALT testing especially for electronics. Examples: Solder joint fatigue, Sn-whisker, corrosion,…
- Highly Accelerated Life Test is a misleading 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.



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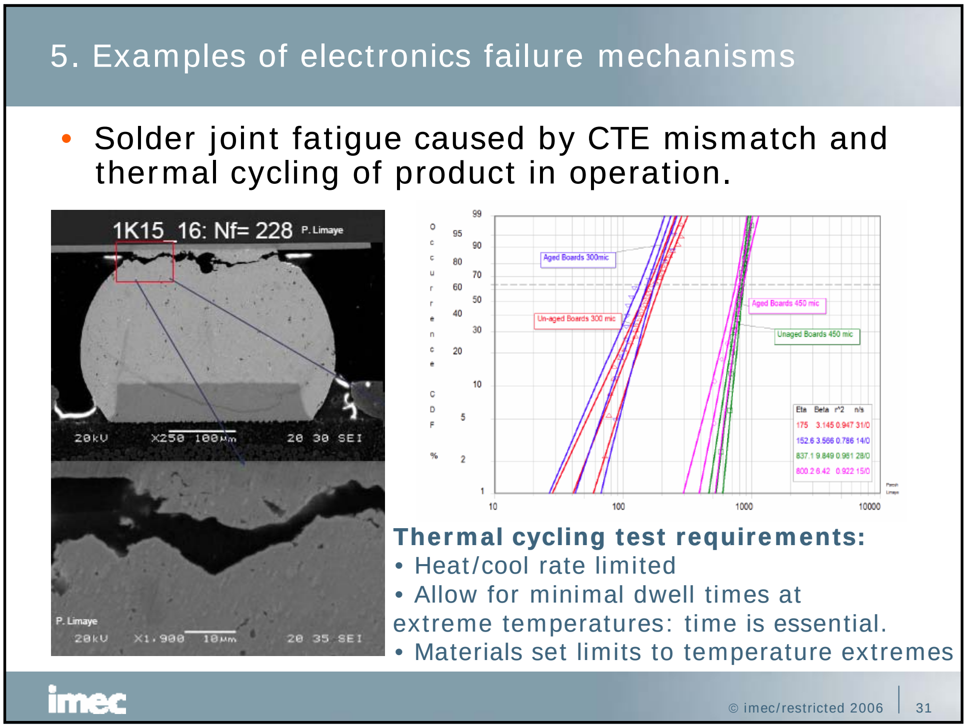
4. Tests supporting Design-for-Reliability

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.

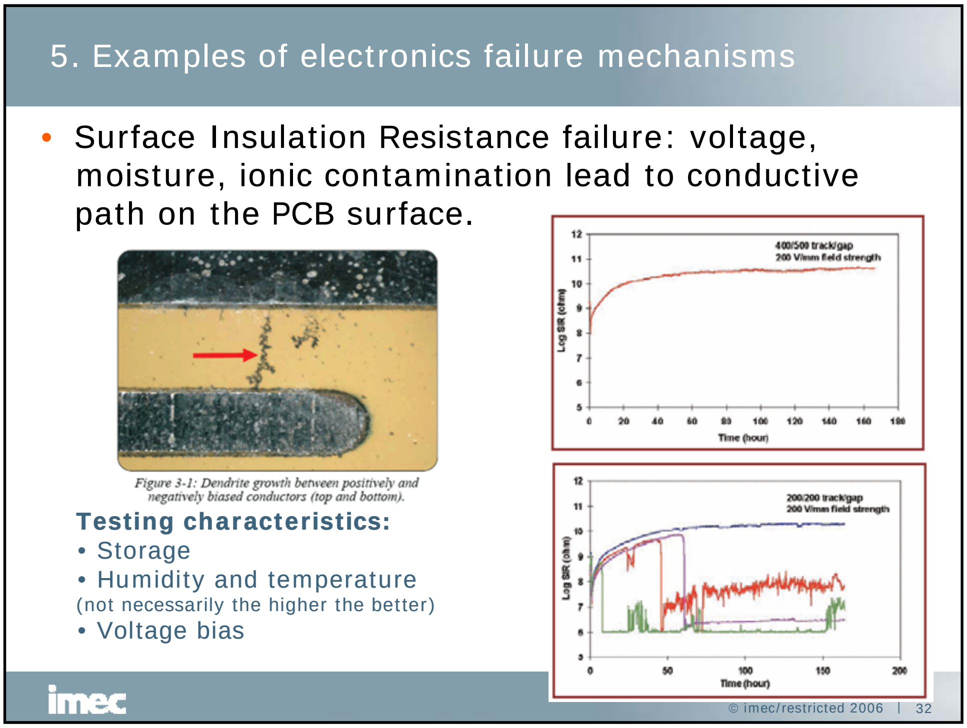


5. Examples of electronics failure mechanisms

- 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



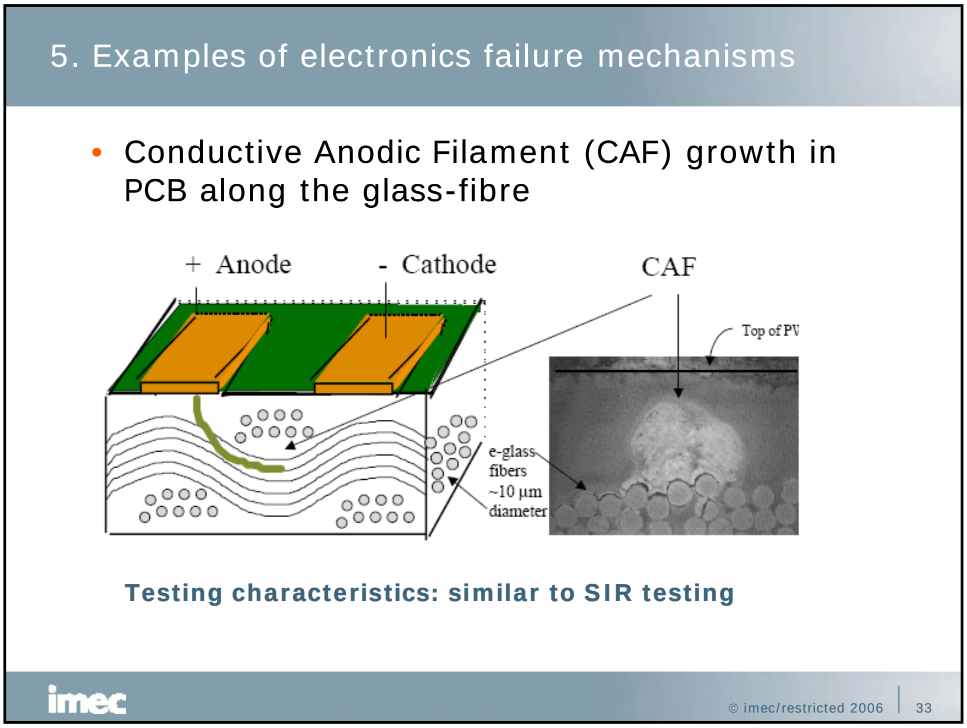
5. Examples of electronics failure mechanisms

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

Figure 3-1: Dendrite growth between positively and negatively biased conductors (top and bottom).

Testing characteristics:

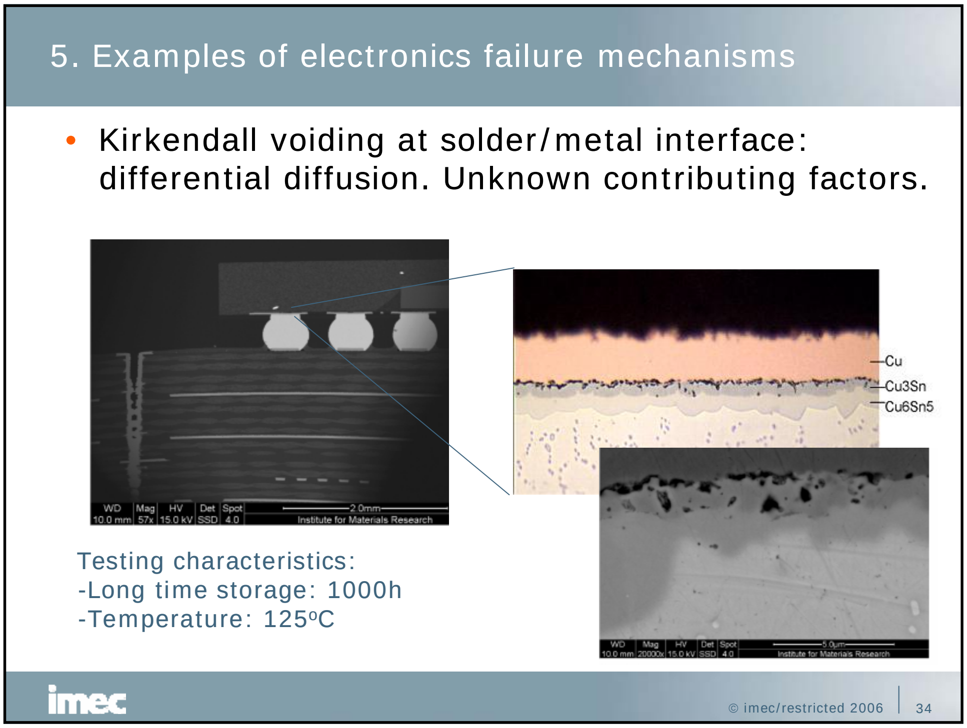
- Storage
- Humidity and temperature
(not necessarily the higher the better)
- Voltage bias



5. Examples of electronics failure mechanisms

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

Testing characteristics: similar to SIR testing



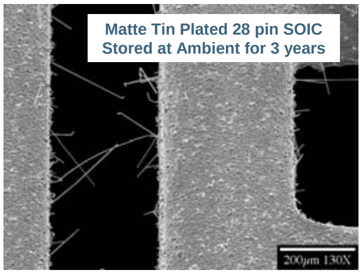
5. Examples of electronics failure mechanisms

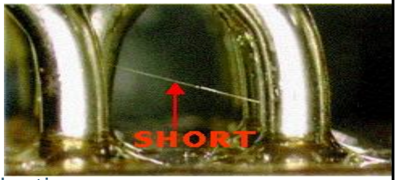
- Kirkendall voiding at solder/metal interface: differential diffusion. Unknown contributing factors.

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





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

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5. Examples of electronics failure mechanisms

And there are many more:
- Hot carrier degradation in Si components
- Electro-migration in conductors
- Dielectric breakdown, degradation
- PCB delamination
- PCB via cracking
- Pop-corning 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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Met steun van: