Electronics Reliability

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- Reliability methodologies
  - Standards-Based Quality Management
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- Failure mechanisms
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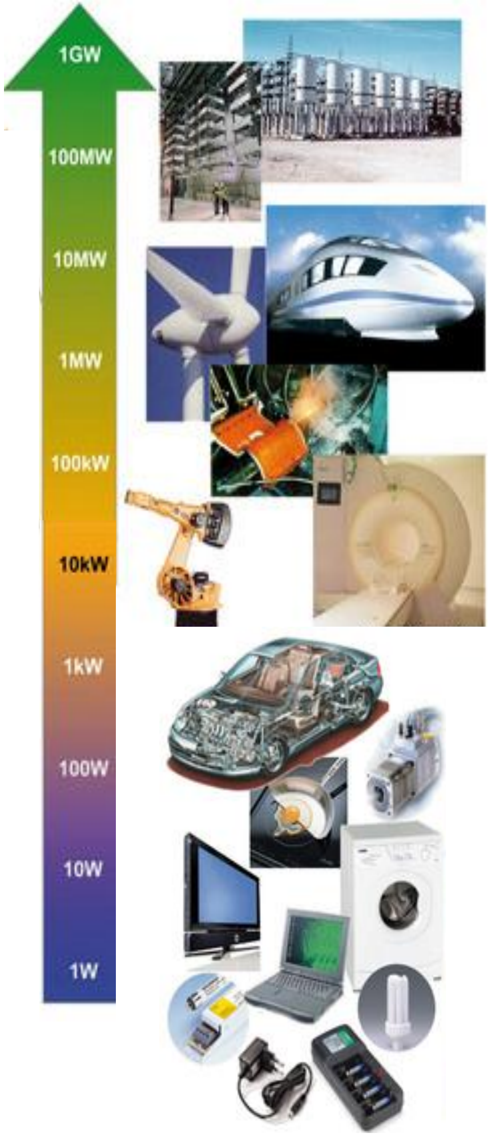
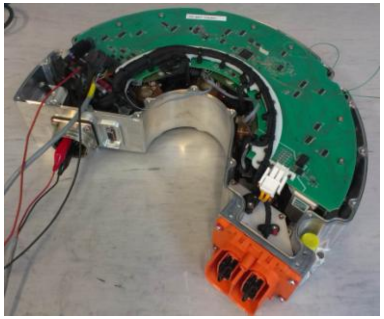
- Future of reliability methodology

Power trends:

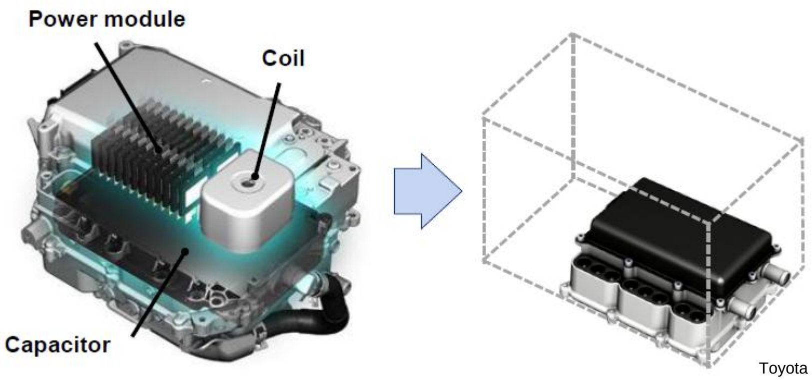
- *Higher switching speeds*
- *Higher power densities*
- *Smaller system volumes*



M. Märtz, ECPE

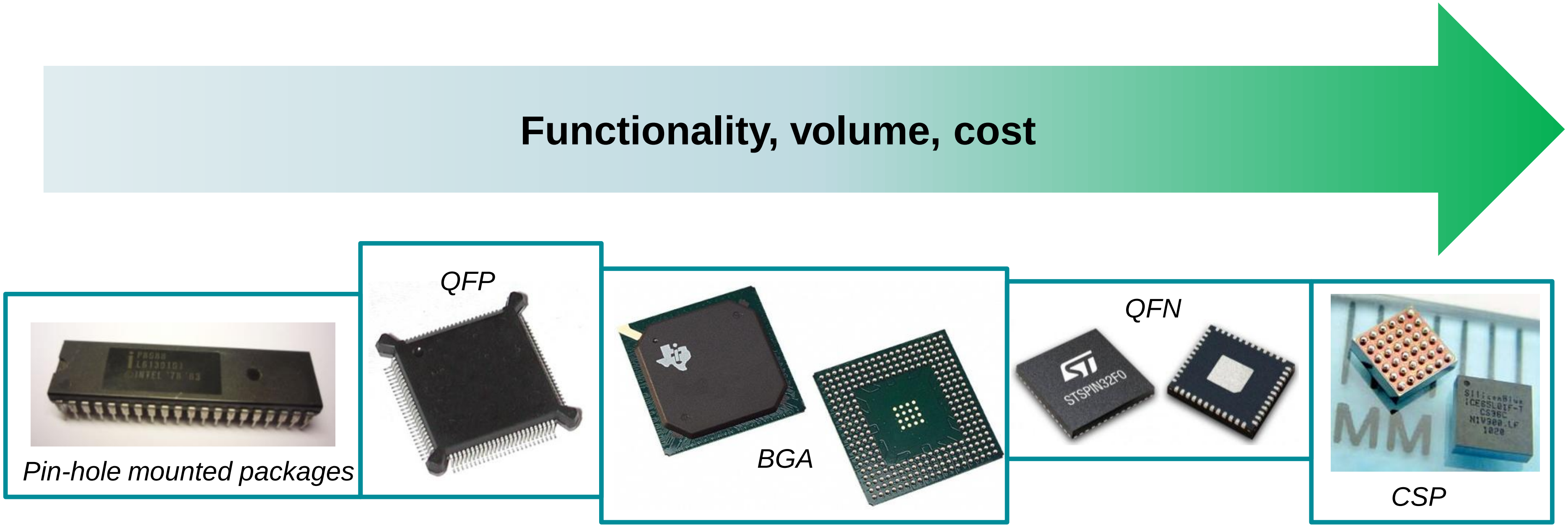


COSIVU project EU FP7



Toyota

Technology is not improving in all aspects



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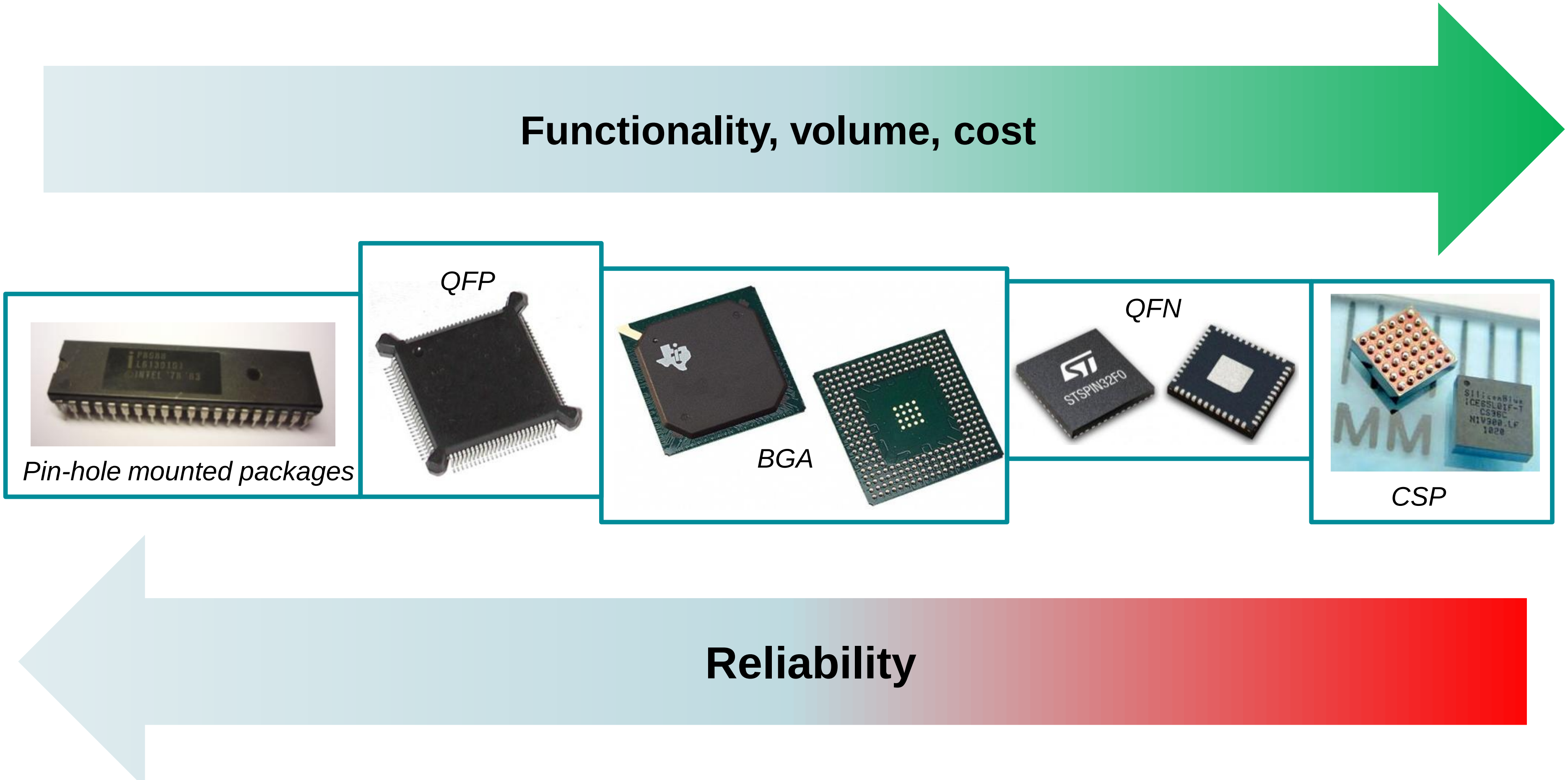
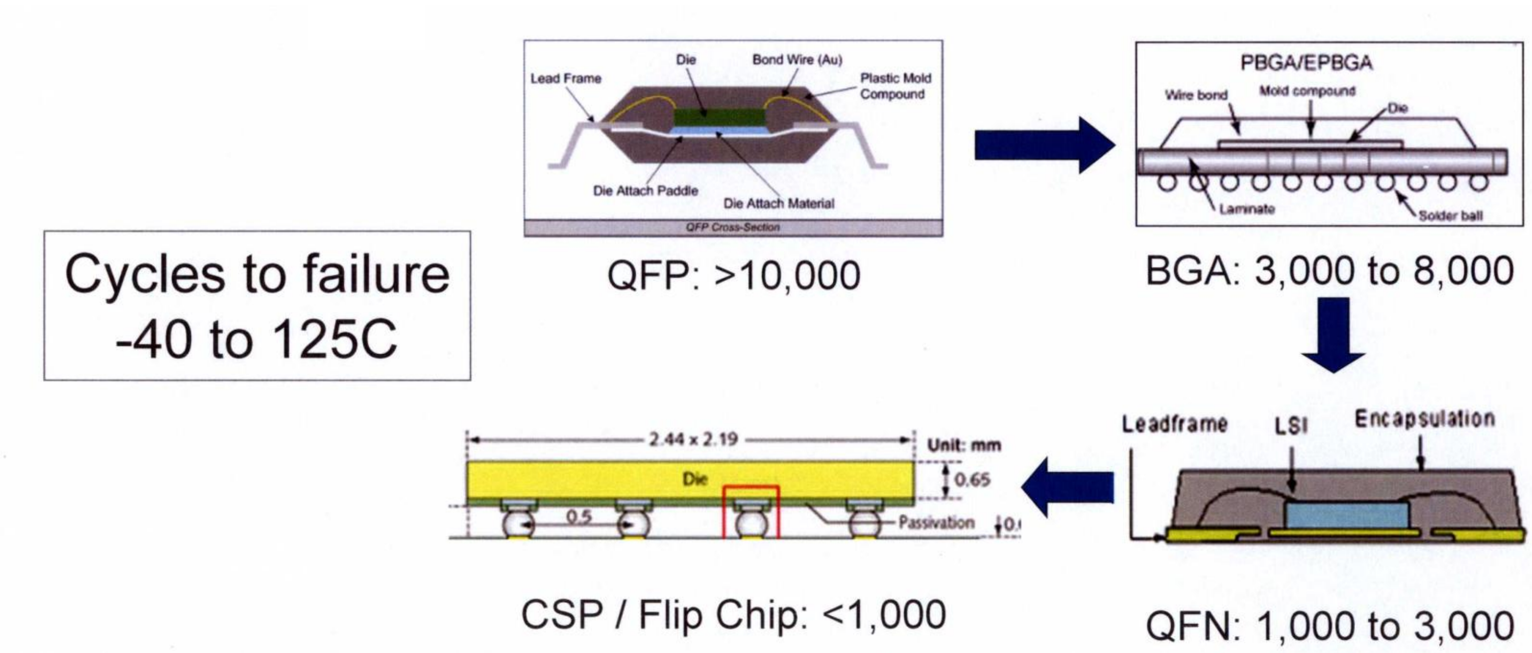


Solder Fatigue From Thermal Cycling - Example



Acceptance criteria for automotive applications according to Carpenter et al. (from 2014):

No failures after 3000 cycles between -40°C and 125°C (cycle time not specified)

Quality, Reliability and Robustness

- ***Quality:*** *Meeting specifications during manufacturing and testing phase prior to shipment.*

- ***Reliability:*** *Meeting specifications during the expected lifetime.*

- ***Robustness:*** *Ability of a product to survive variation beyond specifications.*

- Should reliability and robustness be included in the term quality?
  - Yes or no, depending on which quality management methodology you follow.

Standard-Based Quality Management

- Scientific Management – F. W. Taylor
- WWII – Military equipment from civilian contractors with low quality
- MIL-Q-9858 Quality Program Requirements
- 1950s MIL-standards emerged
  - MIL-STD-785 (reliability program)
  - MIL-STD-781 (reliability demonstration)
  - MIL-STD-217 (reliability prediction)
  - MIL-STD-338 (reliability design)
- 1987 ISO 9000 –third party quality management program and related standards
- In the era of electronics outsourcing, ISO 9000 certification misinterpreted for product quality.
- Other standards: IPC, AEC, SAE, IEEE, …

From ISO 16750:
"ISO 16750 does not necessarily ensure that environmental and reliability requirements for solder joints, solderless connections, integrated circuits, and so on are met. Such items are assured at the part, material or assembly level."

Standard-Based Quality Management

- Developed largely from curve fits of field-failure data
- Gives quantitative estimates often based on incorrect assumptions
  - Constant failure rates (assumes no wearout failures, which isn't true)
  - Semiconductor device failure is assumed to be dominant (which isn't true either)

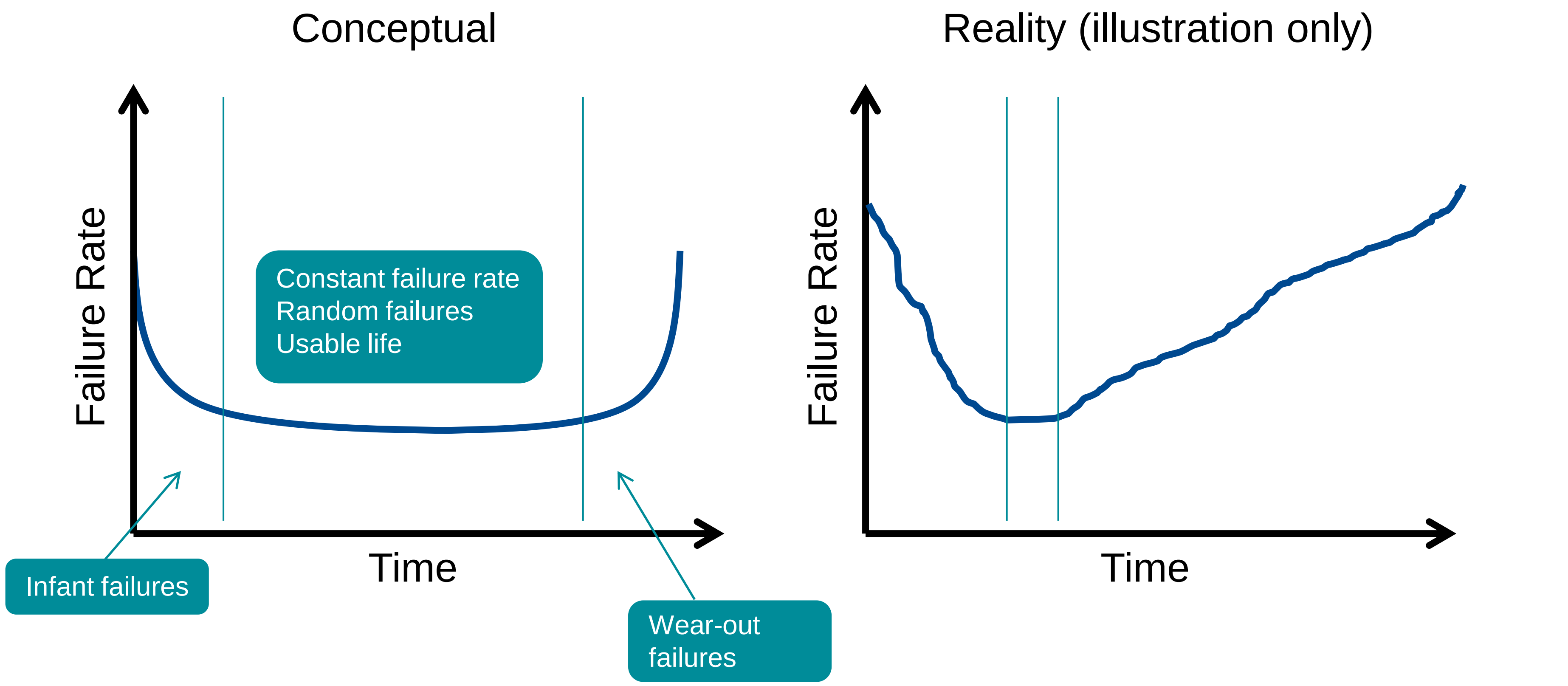
Advantages: Easy to use. Could be ok for products where large amount of field data from relevant application exists and technology has not changed.

Limitations: Has very little, if anything, to do with actual lifetime of a product – this is even stated in the introduction in some of the standards!

- MIL-STD-217F officially cancelled in 1995
- Initiatives to update to G and later H version 10 years later were abandoned after a draft of version G had been developed
- A commercial version of MIL-STD-217F has been developed called PRISM.
- Many companies are still using reliability prediction standards from the 1990s!!

Some words on MTBF (MTTF)

- Bathtub curves are often used to illustrate the infant failures, constant (random) failures and wear-out failures



Some Words on MTBF (MTTF)

- A. Barnard, Lambda Consulting: ”*Reliability predictions of an product as performed today in many industries (MTBF) is an exercise in futility*”.
- Assumes that infant failures are eliminated using stress screening tests and that wear-out failures do not exist.

TABLE 1
Results of 1987 SINCGARS NDI Candidate Test

Vendor	Mil-Hdbk-217 MTBF[1] (hours)	Actual Test MTBF[1] (hours)
A	811	98
B	1269	74
C	1845	2174
D	2000	624
E	2000	51
F	2304	6903
G	2450	472
H	2840	1160
I	3080	3612

[1]The number of significant figures for the MTBFs are as reported by the SINCGARS reliability test & evaluation team. It is unlikely that they reflect both the physical & statistical uncertainties in the data & results.

Cushing, IEEE, Trans. on Rel., 1993

- Assumes failures are caused by semiconductor device failure. Today, a minority of all failures are device failures.
- There is no evidence supporting that calculated MTBF values for components have any relevance.
- So, if the customer/client/company still requires you to make MTBF calculations, what to do?

Recommendation:

Step 1: Find a low-grade engineer (rationale: so that critical resources are not used in this process)

Step 2: Ask the customer what MTBF they would like? 10 years? 50,000 hours?

Step 3: Make various adjustments in the MTBF calculations to provide the customer with the exact MTBF they require, plus a few additional thousand hours for a nice margin.

Alternative method:

- Use MTBF-values from other products – similarity approach (best)
- Use MTBF-values from device manufacturers (2nd best)
- Use MTBF-values from handbooks like MIL-HDBL-217 (worst)

Note 1: Does not capture failures caused by aging or wear-out mechanisms.

Note 2: Does not capture failure caused by manufacturing defects (not even on device level).

Performance (Knowledge) - Based Quality Management

- Requires deep knowledge
- Identifying and modeling physical causes of failure also known as Physics-of-Failure (PoF) approach.

"To eliminate the occurrence of failures, it is essential to eliminate their root causes, and to do that one must understand the physics of the underlying failure mechanisms involved" – Vaccaro, 1962

Advantages: Scientific approach to finding the root cause of failure, which allows for relevant design changes and testing. If done properly will make better predictions of lifetime. Support FE simulations.

Limitations: Complex, costly to apply, and limited for assessing the entire system

- Presented1962 in a series of symposia organized by the US Air Force.
- Gained more attention during the 1990s as it became apparent (as complexity increased) that quantitative methods were inaccurate.
- Provides the strongest characterization of reliability of components, structures and systems.

JEDEC JESD94, Application Specific Qualification Using Knowledge Based Test Methodology (2004)
"Physics of Failure Approach"

1. Determining application specific test requirements
   - Identification of environmental, lifetime and manufacturing conditions
2. Identification of potential failure modes
3. Selection of failure modes for known failure mechanisms
4. Selection of test hardware
5. Selection of stress/reliability tests
6. Selection of test conditions and durations
7. Establish product performance

Other Physics-of-Failure Standards

- ANSI/VITA 51.2
- JEDEC JESD91A, Method for Developing Acceleration Models for Electronic Component Failure Mechanisms
- JEDEC JEP122G, Failure Mechanisms and Models for Semiconductor Devices
- JEDEC JEP148A, Reliability Qualification of Semiconductor Devices Based on Physics of Failure Risk and Opportunity Assessment

Physics-of-Failure Based Standards for Reliability Programs

- IEEE P1332: Reliability Program for the Development and Production of Electronic Products, 1998
- SAE JA1000: Reliability Program Standard, 1998
- ANSI/GEIA-STD-0009: Reliability Program Standard for Systems Design, Development, and Manufacturing, 2008

The approach in these can be summarised in three points:

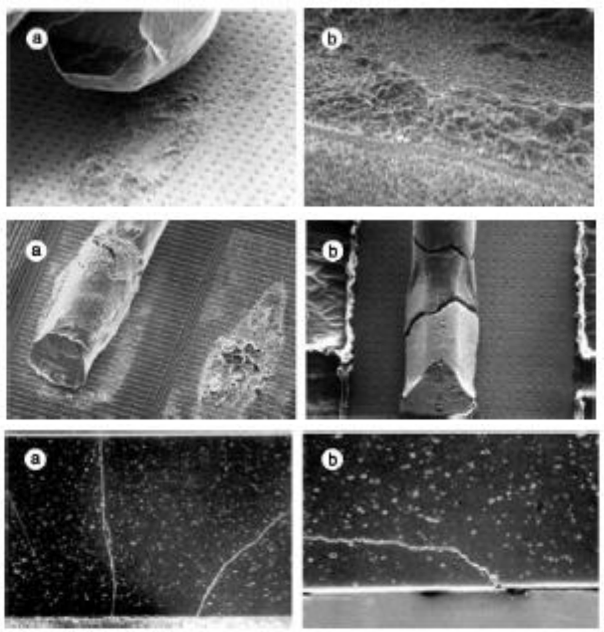
- Progressive understanding of the system-level operational and environmental loads and the resulting loads and stresses that occur throughout the structure of the system;
- progressive identification of the resulting failure modes and mechanisms;
- aggressive mitigation of surfaced failure modes.

The focus is on **risk management**, i.e. identification and minimisation of the risks for reliability problems, both regarding the product and production processes.

Failure Mechanisms in Power Electronic Assemblies

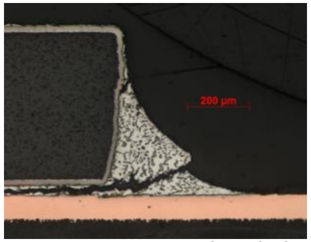
A majority of failure mechanisms in power devices are driven by thermo-mechanical stresses.

- Wire bond related failures
- Delamination and cracking
- Solder fatigue

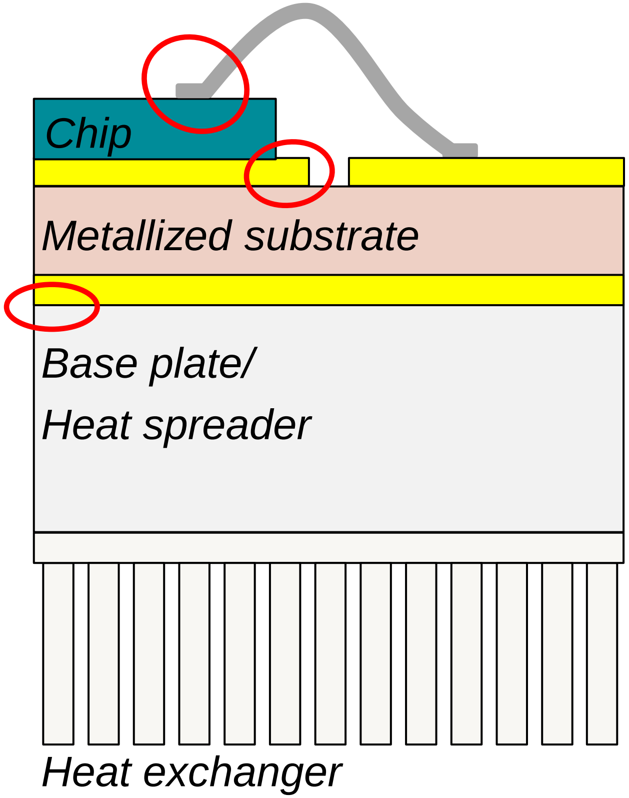


M. Ciappa, Microelectronics Reliability 42 (2002) 653–667.

Ingo Graf, Infineon



Dfr Solutions



Lifetime Prediction Models – Solder Fatigue (Lead Free)

Palmgren-Miner: $$\mathrm{LC} = \sum_{i}^{k} \frac{n_i}{N_{fi}}$$

Arrhenius: $$N_f = Ae^{E_a/(k \times T_m)}$$

Coffin-Manson: $$N_f = \alpha \times (\Delta T_j)^{-n}$$

Coffin-Manson-Arrhenius $$N_f = \alpha \times (\Delta T_j)^{-n} \times e^{E_a/(k \times T_m)}$$

Engelmeier $$N_\mathrm{f} = \frac{1}{2}\left[\frac{\Delta\gamma_t}{2\varepsilon_\mathrm{f}'}\right]^{1/c}$$

$$c = c_o + c_1 T_{sj} + c_2 \ln(1 + f)$$

Norris-Landzberg $$AF = \frac{N_{field}}{N_{test}} = \left(\frac{f_{field}}{f_{test}}\right)^m \left(\frac{\Delta T_{test}}{\Delta T_{field}}\right)^n \left(e^{\frac{E_a}{k}\left(\frac{1}{T_{max,field}} - \frac{1}{T_{max,test}}\right)}\right)$$

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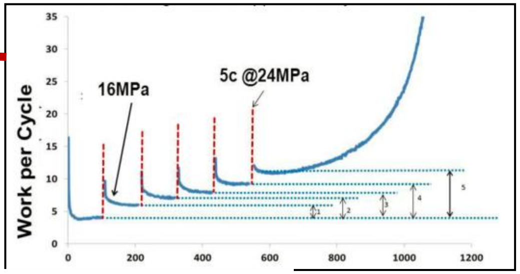

Borgesen, EuroSimE 2014

After each excursion to higher amplitude the damage per cycle at the lower amplitude is greater

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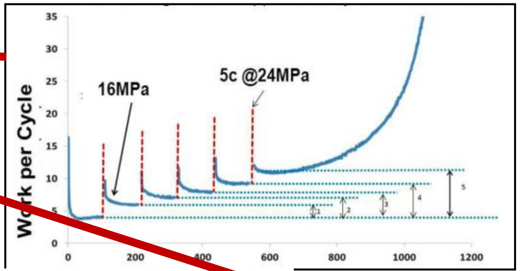

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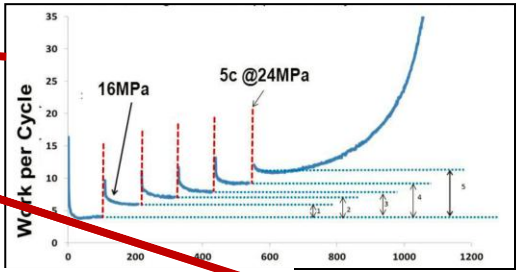

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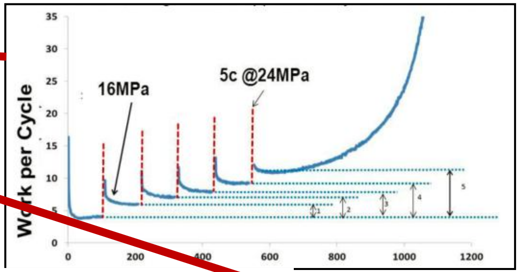

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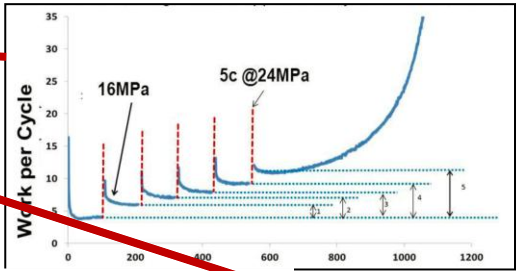

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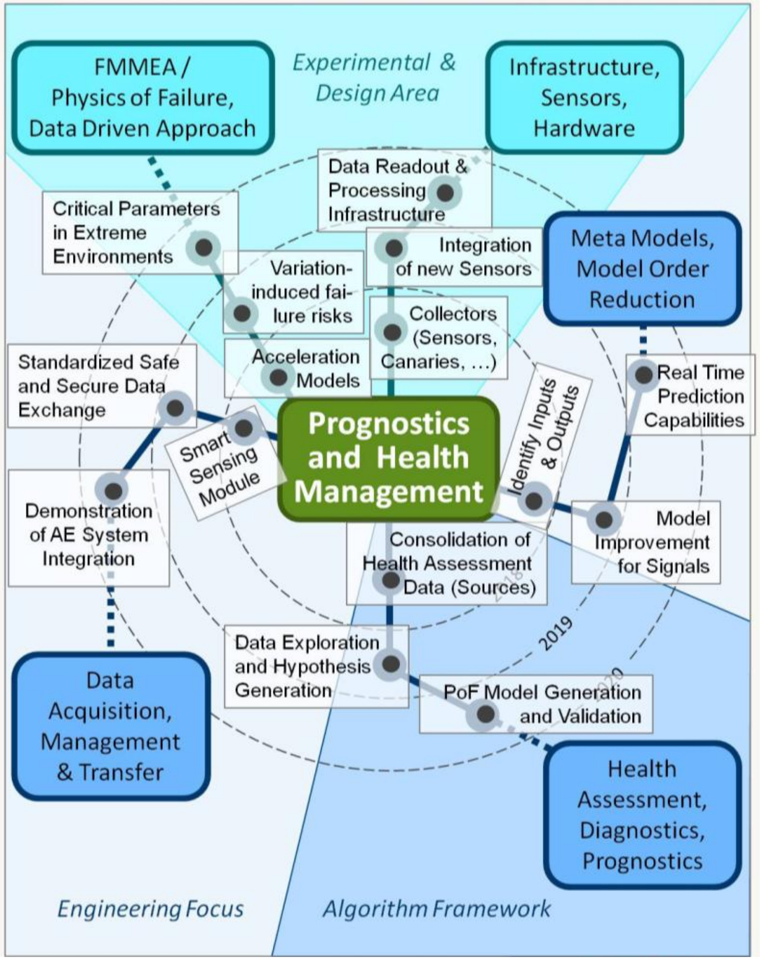
Conclusion: We are not there yet. The models need to be improved to account for, for example:
-Microstructure effects.
-Effect of precipitates.
-How to handle combined thermal/vibration/humidity loads.

Prognostics and Health Management (PHM) – the next steps in reliability management

- Continuous, real-time assessment of remaining useful life (RUL).
- Increases availability of the system
- Could remove redundancy.
- Established for simple systems like rotating machinery and structural engineering.
- Electronics much more complicated.
- Requires a multidiciplinary approach.
- Efficient management of impending failures saves costs and guarantees system availability.



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It is difficult to make predictions, especially about the future.

- Karl Kristian Steincke

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