CEDM EVENT 2017

RELIABILITY OF ELECTRONICS: A PHYSICS-OF-FAILURE APPROACH

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Electronics Design & Manufacturing

Met steun van:

AGENTSCHAP INNOVEREN & ONDERNEMEN

CONTENT

SECURITY VERSUS RELIABILITY

Reliability:

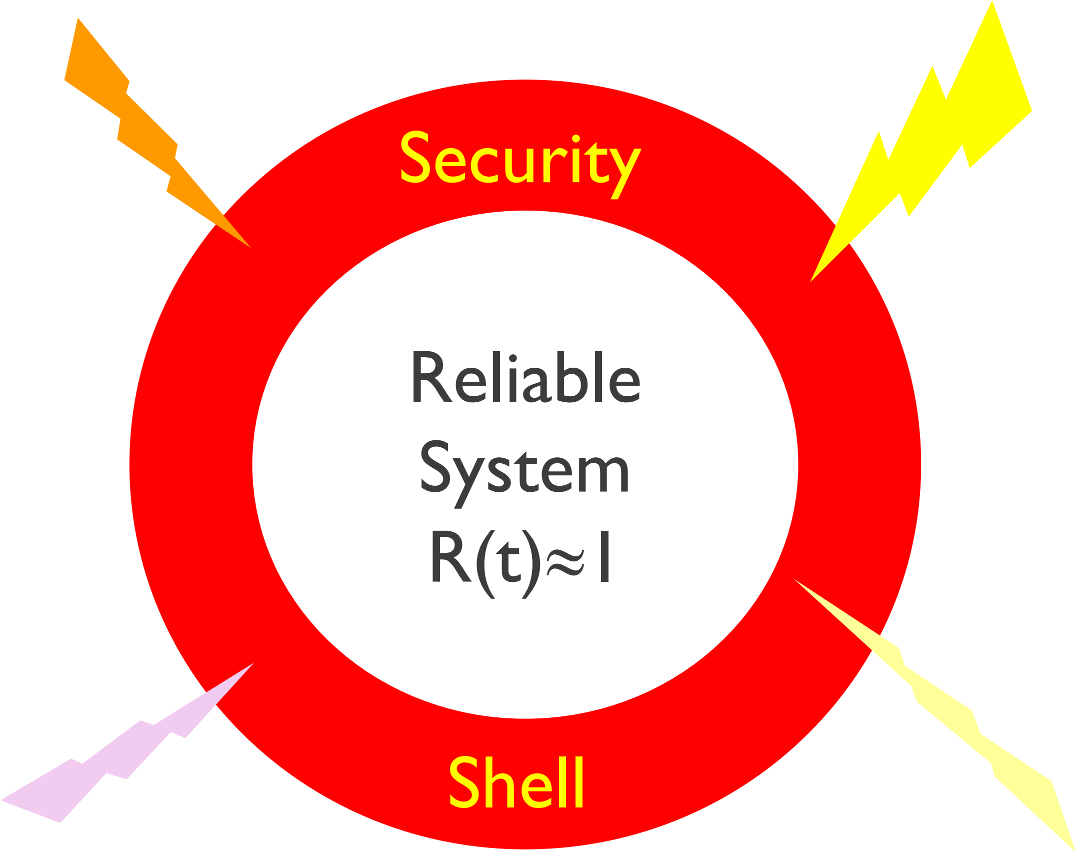
Ability of a system to perform its required functions under stated conditions for a specified period of time.

Security:

Ability of a system to protect information and system resources with respect to confidentiality and integrity.

→ Not vulnerable to intruders.

SECURITY VERSUS RELIABILITY



- Reliability is concerned with internal, functional aspects. Security deals with attacks from intruders.
- By differentiating we better understand the system and take actions in consequence.
- If a system is not reliable the security of that system is just a fuzzy topic.

(George Iordache, Stony Brook University)

THE ELECTRONICALLY CONNECTED WORLD

McKinsey&Company


INTERNET OF DATA
BROWSING
ANTWERPEN.BE
SMARTPHONE
CALLING
2min 03sec
INTERNET OF THINGS
SMARTWATCH
INTERNET OF HUMANS

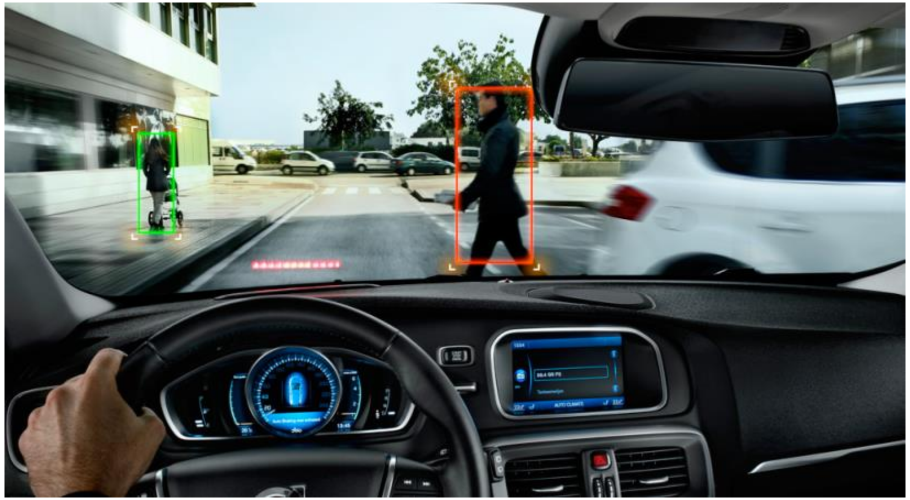
City of Things

CONNECTED CAR

DIANNE TECHNOLOGY

Real-time execution by the AI-enabled point

Knowledge base & Deep learning in the Cloud



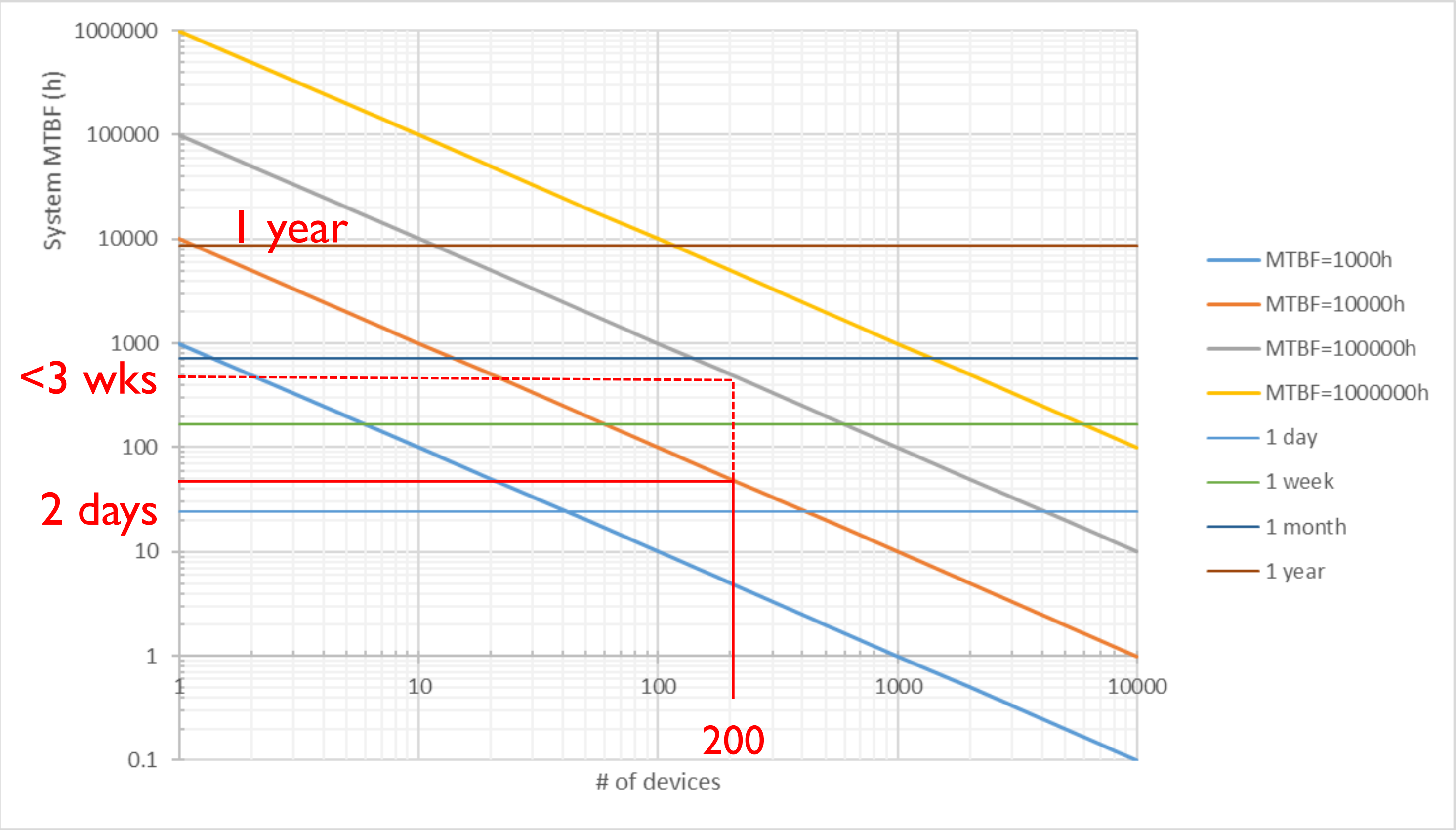
Push new samples to experience pool

Get optimized NN training results

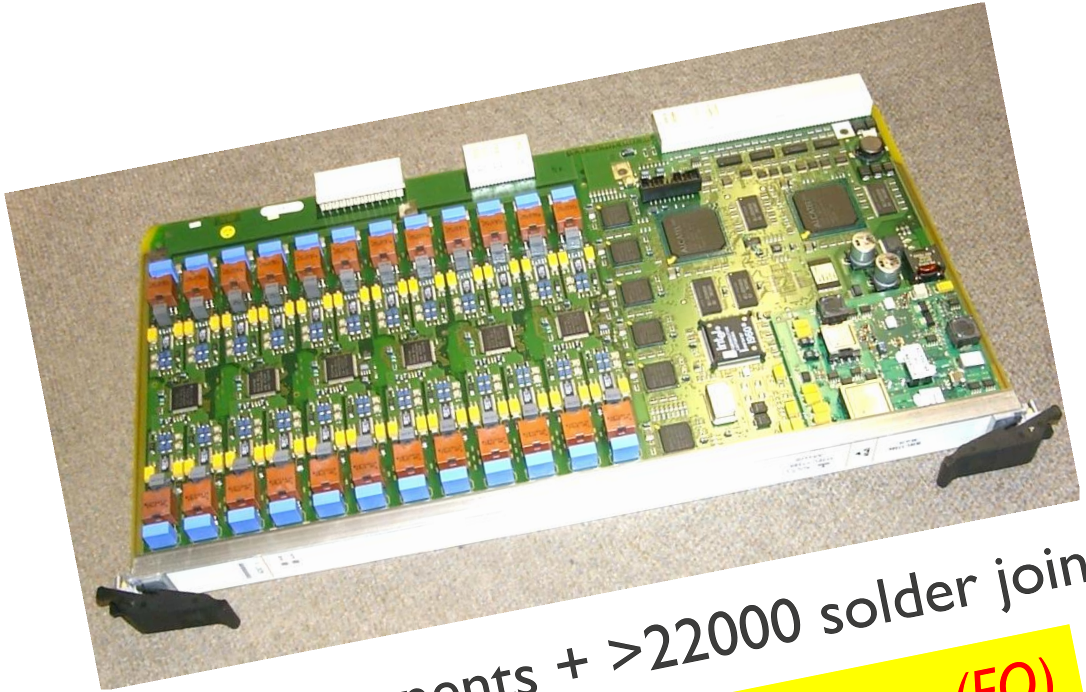
WHY WE NEED RELIABILITY?

TIME BETWEEN FAILURE

In the Connected world Reliability is Essential



THE RELIABILITY QUANTIFICATION CHALLENGE
SO MANY THINGS CAN FAIL …



2500 components + >22000 solder joints

= >40000 failure opportunities (FO)

Components

Solder joints

PCB

PBA

1 PBA =(1K to 100K FO)
x *n* failure mechanisms/FO

THE TRADITIONAL APPROACH
RELIABILITY PREDICTION STANDARDS

MIL-HDBK-217 - *the oldest, best-known most outdated (1995)*

Telcordia SR-332 - *previously Bellcore, telecommunication, US.*

IEC-61709/SN 29500 - *Siemens, industrial, Germany.*

IEC-TR-62380/Fides 2009 - *French industry, industrial-avionics, France.*

217plus – *Quanterion, commercial MIL-HDBK-217 update, US.*

GJB/Z 299C – *China.*

Describe how to determine the reliability of a **system of** electronic **components** using **constant failure rate statistics** and field failure data.

Basic principle: $\lambda_{sys} = \lambda_1 + \lambda_2 + \lambda_3 + \ldots + \lambda_n + \lambda_{PCB}$

THE TRADITIONAL APPROACH

CONSTANT FAILURE RATE: WHAT DOES IT MEAN?

Buy NEW

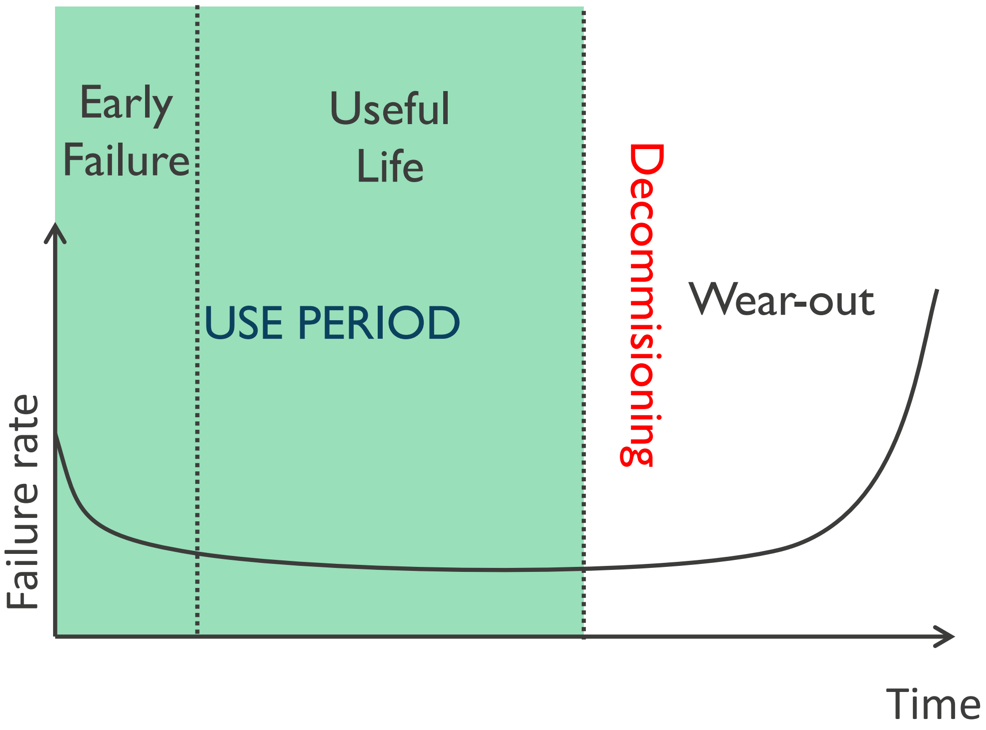
Buy USED

Do you expect the same failure rate for a used car as for a new one?

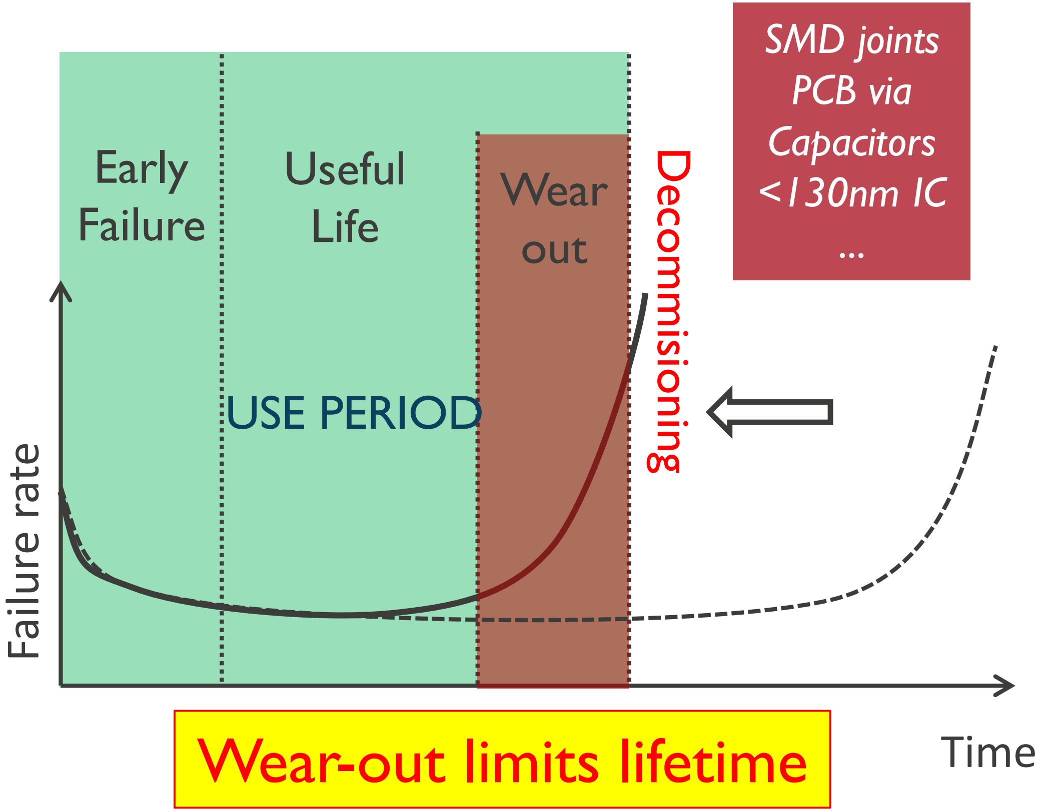
THE TRADITIONAL APPROACH

THE REAL WORLD

What it was (before the '80s)



What is now!



THE TRADITIONAL APPROACH

STRESS FACTORS AND FAILURE RATE

Semi-empirical/statistical treatment of stress and quality.

Failure rate
Semiconductor
Component

IEC TR-62380

MATHEMATICAL MODEL :

$$\lambda = \left(\underbrace{\left\{ \lambda_1 \times N \times e^{-0.35 \times a} + \lambda_2 \right\} \times \left\{ \frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right\}}_{\lambda_{die}} + \left\{ \underbrace{2.75 \times 10^{-3} \times \pi_\alpha \times \left(\sum_{i=1}^{z} (\pi_n)_i \times (\Delta T_i)^{0.68} \right) \times \lambda_3}_{\lambda_{package}} \right\} + \left\{ \underbrace{\pi_I \times \lambda_{EOS}}_{\lambda_{overstress}} \right\} \right) \times 10^{-9} / h$$

NECESSARY INFORMATION:

$(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during

$(t_{ac})_i$: oard (PCB) near the compon

λ_1 : d circuit family. See Tab

λ_2 : g of the integrated circuit

N : number of transistors of the integrated circuit.

a : [(year of manufacturing) – 1998].

$(\pi_t)_i$: i^th temperature factor related to the i^th junction temperature of the integrated circuit mission profile.

τ_i : i^th working time ratio of the integrated circuit for the i^th junction temperature of the mission profile.

This is not physics!

Quality factors allow failure rate range 1 to 8000 (FIDES)

TRADITIONAL APPROACH
WHY IS IT STILL USED?

- *"We have always done it that way."*
- The method is (still) accepted in industry.
- It is more or less comprehensive.
- It always gives a number.
- It is relatively simple to use (summation).
- Provides a lot of stretch... (1 – 8000)
- Lack of Physics-of-Failure know-how at user side.

THE PHYSICS-OF-FAILURE APPROACH
DEFINITION

A science-based approach to reliability that uses modeling and simulation to design-in reliability.

It helps to understand system performance and reduce decision risk during design and after the equipment is fielded. This approach **models the root causes of failure** such as fatigue, fracture, wear, and corrosion.

An approach to the design and development of reliable product to prevent failure, based on the knowledge of root cause failure mechanisms. The Physics of Failure (PoF) concept is based on the **understanding of the relationships** between requirements and the physical characteristics of the product and their variation in the manufacturing processes, and the **reaction of product elements and materials to loads (stressors)** and interaction under loads and their influence on the fitness for use with respect to the use conditions and time.

THE PHYSICS-OF-FAILURE APPROACH
THE BASICS

1. Quantitative physical model of the failure mechanism.
   - Fatigue failure: solder joints, PCB via's & tracks.
   - Diffusion and evaporation of liquids: degradation of Al-capacitors.
   - Electro-migration (electric field driven) and corrosion.
   - …

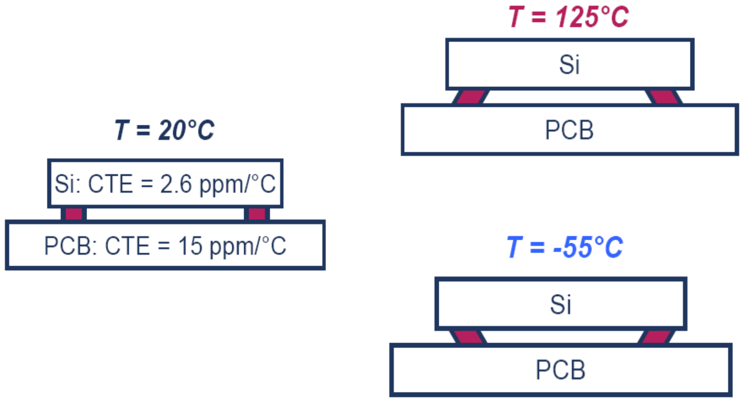
2. Calculation of the stress level dependent "damage factor" determining the lifetime.

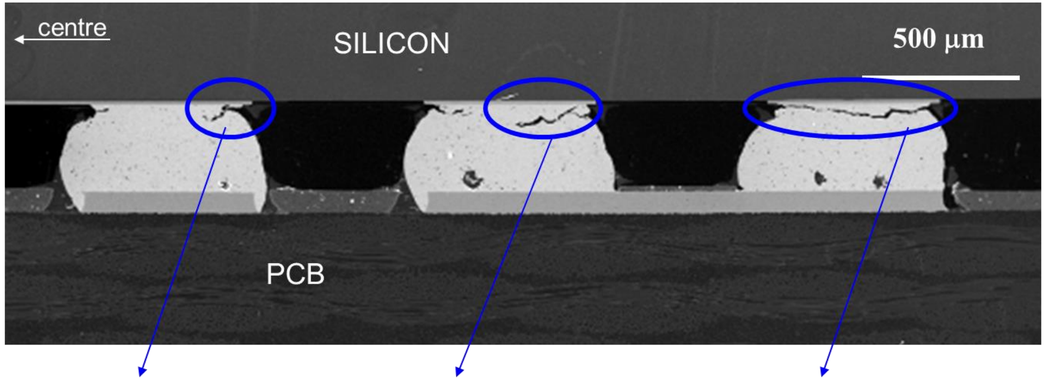
3. Apply (empirical) lifetime model: lifetime = F("damage factor")
   (e.g. Wöhler curve)

THE PHYSICS-OF-FAILURE APPROACH

AN EXAMPLE: SOLDER JOINT FATIGUE DUE TO THERMAL CYCLING

Failure Mechanism

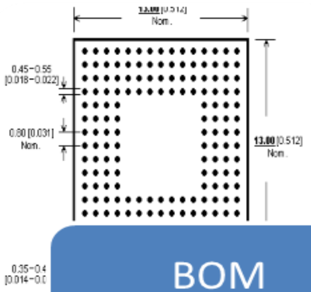




THE PHYSICS-OF-FAILURE APPROACH

AN EXAMPLE: SOLDER JOINT FATIGUE DUE TO THERMAL CYCLING

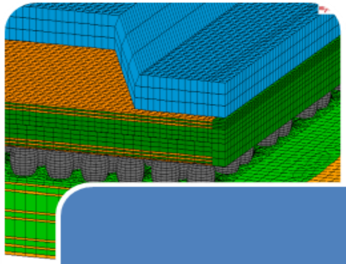
Quantification



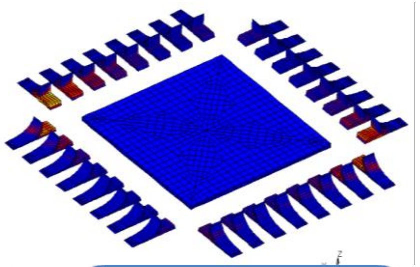
BOM

+

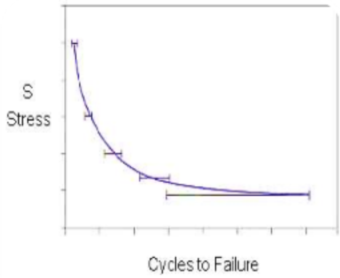
Mission profile



Modelling / Quantification / Simulation



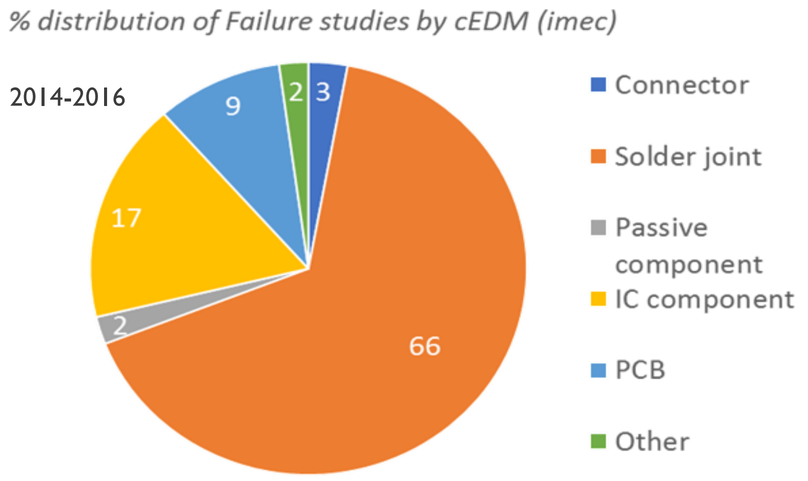
Cyclic strain in solder joints



Life time model

THE PHYSICS-OF-FAILURE APPROACH

RELIABILITY OF A SYSTEM



$$\lambda_{sys} = \lambda_1 + \lambda_2 + \lambda_3 + \ldots + \lambda_n + \lambda_{PCB}$$

is not valid.

How to handle?

- Identify all failure opportunities (EDM-D-100 – www.cedm.be)
- PoF based reliability function $R_i(t)$ *per FO*.

  $R_i(t)$: Probability that no failure has occurred at time *t* at failure opportunity *i*.

- For a system without redundancy: $$R_{sys}(t) = \prod_{\forall \text{ Fail.Opp.}} R_i(t)$$

THE PHYSICS-OF-FAILURE APPROACH

OBTAINING *R(t)* FOR 1000 TO 100000 FAILURE OPPORTUNITIES?

What do we need?

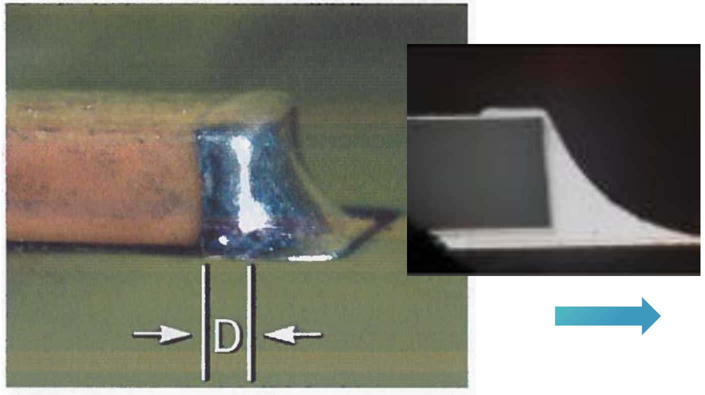
- Quantified understanding of the relationship between design and mission profile and the probability of failure.
- Fast (seconds) quantification of $R_i(t)$ for all (relevant) failure opportunities to evaluate a PBA in an acceptable time.

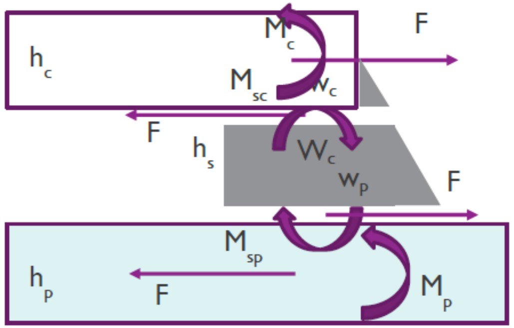
The answer: Analytical modeling

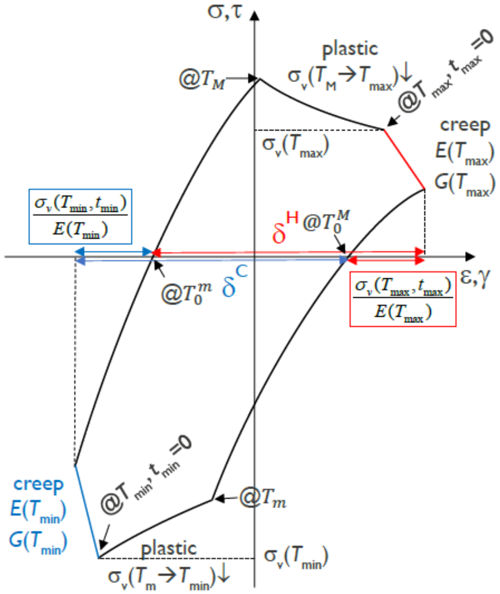
- Physics-based equations that directly relate the stress factors to the "damage factor".
- Complete physical understanding and insight.
- "immediate" calculation of required answer with basic tools, even Excel.

THE PHYSICS-OF-FAILURE APPROACH

AN EXAMPLE: SOLDER JOINTS OF A "CHIP" COMPONENT







$$\frac{L-w_c}{2}\left[(\alpha_p-\alpha_c)(T_{max}-T_0^m)-F_{max}(s_h,T_{max},t_{max})\left(\frac{1}{E_p h_p b_p}+\frac{1}{E_c h_c b_c}\right)\right]$$

$$-\frac{L-w_c}{2}\left[\left(1+\frac{\alpha_p+\alpha_c}{2}(T_{max}-T_0^m)\right)\left(\frac{h_p+h_s}{2}\frac{M_p^{max}(T_{max})}{E_p I_p}+\frac{h_c+h_s}{2}\frac{M_c^{max}(T_{max})}{E_c I_c}\right)\right]=\delta^H$$

Elastic/plastic/creep, bending, 2D/3D, temperature, dimensions, fillet, materials, ...

THE PHYSICS-OF-FAILURE APPROACH

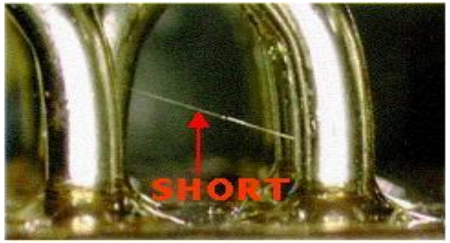
ANALYTICAL ANALYSIS: CHALLENGES AND LIMITATIONS

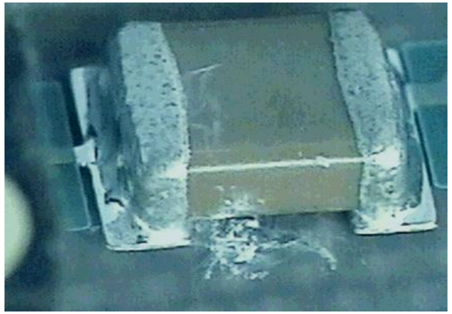
Not all failure mechanisms are understood quantitatively. E.g. whisker growth.

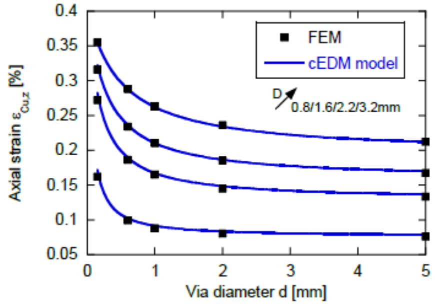
Model parameters cannot be obtained with the required accuracy. E.g. corrosion.

(Still) limited availability of sufficiently accurate analytical models. Effort to develop the analytical models.

Acceptance by industry of analytical modeling/evaluation.







PHYSICS-OF-FAILURE IN PRACTICE TODAY

ELIMINATING FAILURE OPPORTUNITIES: THE UNKNOWNS

Step 1: Know what you do not know!

Identify failure opportunities for which the wear-out failure mechanism is unknown, lifetime cannot be assessed, ...

Exotic cases? Applies to the major part of the components!

Action:

- Document, register as unknown (and hope for the best(1))...
- ... or start some research and test.

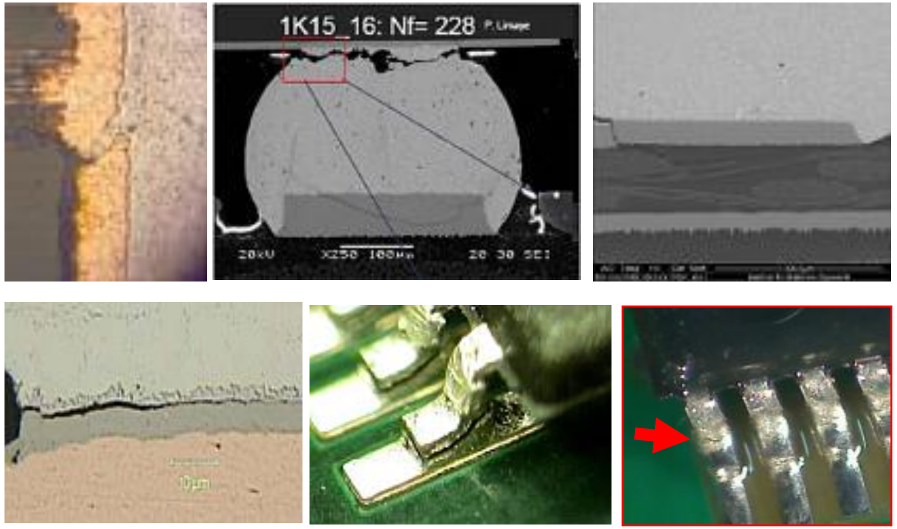
(1): Some may find some peace of mind by using constant failure rate modeling. It has no added value w.r.t. to wear-out.

PHYSICS-OF-FAILURE IN PRACTICE TODAY

ELIMINATING FAILURE OPPORTUNITIES: QUANTIFICATION VS. MITIGATION

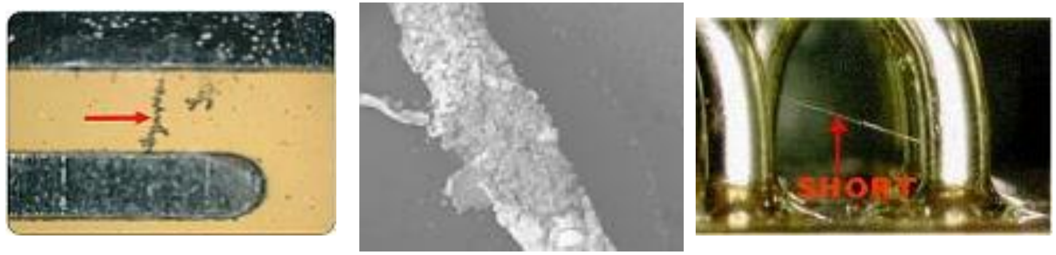
Step 2 ***Quantification*** versus ***Mitigation***

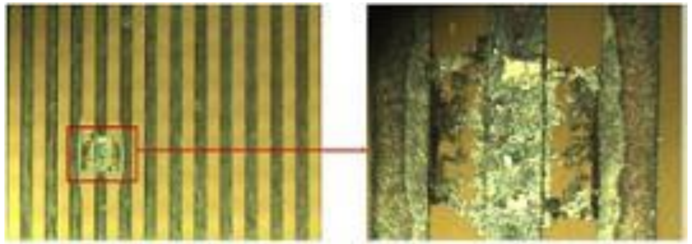
Connection failure



Quantifiable with PoF:
Thermo-mechanical stress

Insulation failure





PoF:
How to avoid

- Material specification e.g. fluxes
- Coating
- Environmental protection

$R_i(t)=1$

PHYSICS-OF-FAILURE IN PRACTICE TODAY

ELIMINATING FAILURE OPPORTUNITIES: NOT CRITICAL

Step 3: Eliminate non-contributors using FMEA.

E.g. Solder joint fatigue (see EDM-D-002)

Not critical:

- Through-hole connections
- Components with flexible leads
- Components soldered to thin and/or flexible boards

Critical:

- Large SMD ceramic chip components ≥1810
- QFN > 4mm x 4mm

This requires some PoF expertise.

PHYSICS-OF-FAILURE IN PRACTICE TODAY

STEP 4: MODELS & TOOLS

Scientific literature:

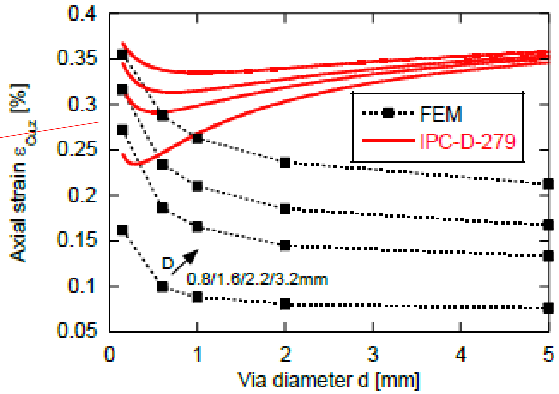
- Often too detailed (in-depth), complicated, hard to implement and use.
  For scientific use not for industrial implementation.
- Far from complete.

Standards:

- IEEE 1413-2010: Reliability Prediction of Hardware (IEEE 1413.1: Guide)
- Physics of Failure Reliability Prediction ANSI/VITA 51.3 (2016)

Models:

- Large empirical part including "quality" factors
- Limited number effects taken into account.
- Not very accurate e.g. IPC-D-279
  (solder joint and via fatigue model)



PHYSICS-OF-FAILURE IN PRACTICE TODAY

MODELS & TOOLS

Physics-of-Failure based tools combining DfR FMEA, numerical and analytical modeling

CALCE's SARA

https://www.calce.umd.edu/software/

DfR Solutions' Sherlock

http://www.dfrsolutions.com/what-is-sherlock

CONCLUSION

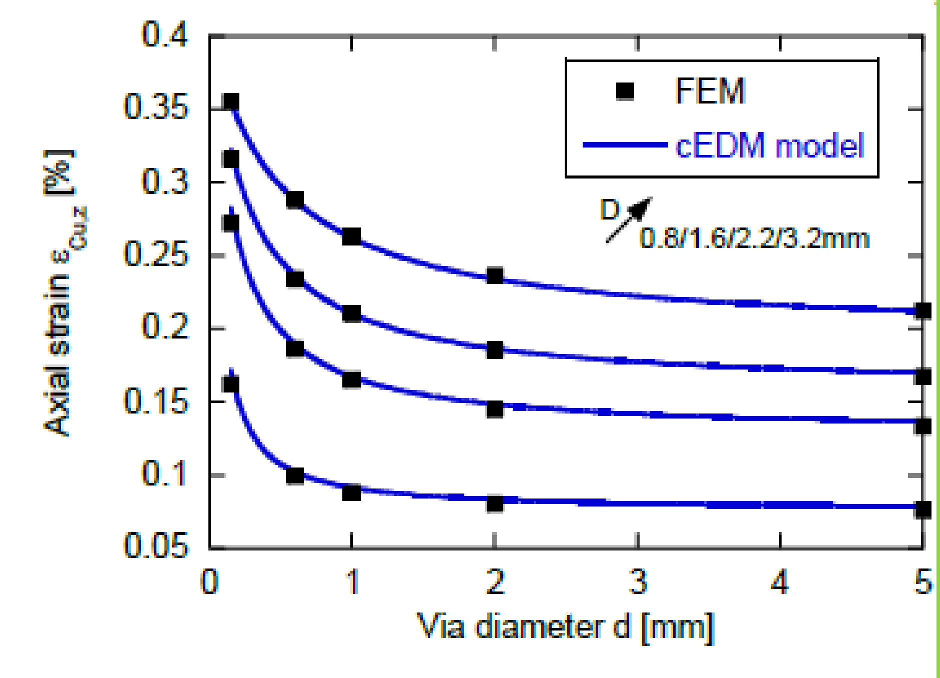
The reliability of electronics is of increasing importance

A Physics-of-Failure based reliability assessment is the only viable approach to lifetime assessment of modern electronics.

Analytical modeling is pivotal in providing physical insight, fast and sufficiently accurate analysis, increasing the coverage and ease of use.

It is not easy but we can help.

Modeling
Tools
Guidelines
Assistance



INPROVOL

Is InProVoL of interest to you?

Join the 30 companies/organisations in the VIS-traject InProVoL community

- Join user committee
- Join the InProVoL consortium as cEDM partner or member
  (InProVoL consortium member fee is covered by cEDM partner/membership)
- Contact Bart.Cox@imec.be - +32 16 283108 - +32 478 252316
- Project leader Bart.Vandevelde@imec.be - +32 16 281513 - +32 473 694157

THANK YOU

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