KNOWLEDGE BASED QUALIFICATION
MEETING CHALLENGES OF NEW MARKETS AND NEW TECHNOLOGIES

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Intel

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https://inemi.webex.com/inemi/lsr.php?RCID=be32b5ae6db049ebac004d0118d888d7

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ELECTRONICS EVERYWHERE
NEW USAGE MODELS

SMALLER FEATURES
HIGH COMPLEXITY

RAPID PROLIFERATION
SHORT TTM


TeleComm Era
Internet Era
“Smart” Era
Productivity Era

Rapid Proliferation
Short TTM
HOW TO DEFINE QUALIFICATION CRITERIA TO CONTINUOUSLY MEET CUSTOMER’S Q&R NEEDS WHEN TECHNOLOGY IS RAPIDLY CHANGING?
Reliability response choices

**STANDARDS (STRESS) BASED QUALIFICATION (SBQ)**
Product is “as good” as past products

“We did the same as the rest of the industry”

**KNOWLEDGE BASED QUALIFICATION (KBQ)**
Product engineered for real usage

“We did what was necessary to protect the customer”

Intel’s approach: **Knowledge Based Qualification (KBQ)**
OUTLINE

- KBQ: Fundamental Building Blocks
- KBQ: Understanding Use Conditions
- KBQ: Capturing the Physics
- Implications and Examples
- Conclusions
Use Conditions (UC)

Physics of Failure (PoF) based failure metrics

PoF and UC Based Reliability models and requirements

Well Controlled Component Test

Quality & Reliability

Design for Reliability

Cost

Survey

UC Behaviors Scenarios

Customer Tests Envelope

Measurements
User behavior and operating conditions can drive failure.
USE CONDITIONS: SBQ VS. KBQ

SBQ: Rudimentary understanding of UC

KBQ: Measured usage

KBQ quantifies UC. It can be complicated but it is very important!
OUTLINE

- KBQ: Fundamental Building Blocks
- KBQ: Understanding Use conditions
- KBQ: Capturing the physics
  - Challenges with Standard (Stress) Based Qual (SBQ)
  - Overcoming challenges of SBQ
- KBQ: Implications and Examples
- Conclusions
STANDARDS
<table>
<thead>
<tr>
<th>Name</th>
<th>Empirical acceleration model/equation</th>
<th>Primary stress</th>
</tr>
</thead>
</table>
| Coffin-Manson         | \[
\frac{N_{use}}{N_{test}} = \left( \frac{\Delta T_{use}}{\Delta T_{test}} \right)^{-n}
\]                                | \(\Delta T\)                 |
| Norris-Landzberg      | \[
\frac{N_{use}}{N_{test}} = \left( \frac{\Delta T_{use}}{\Delta T_{test}} \right)^{-n} \left( \frac{f_{use}}{f_{test}} \right)^{m} e^{1414 \left( \frac{1}{T_{hi,use}} - \frac{1}{T_{hi,stress}} \right)}
\]                | \(\Delta T, Tmax\)          |
| Peck                  | \[
\frac{N_{use}}{N_{test}} = \left( \frac{RH_{use}}{RH_{test}} \right)^{-n} \text{Exp} \left( \frac{E_{a}}{k} \right) \left[ \frac{1}{T_{use}} - \frac{1}{T_{test}} \right]
\]                    | RH-relative humidity         |
| ...........           | ...........                                                                                           | .......                       |
Reliability Risk Assessment vs. Field Risk

Qual Requirements

\[ \frac{N_{\text{use}}}{N_{\text{stress}}} = \left( \frac{\Delta T_{\text{use}}}{\Delta T_{\text{stress}}} \right)^{-n} \]

Not impacted by brd. thickness

Impacted by board thickness

Use Condition Risk

FLI Stress (normalized)

Ex: FLI qualification
ACCOUNTING FOR GEOMETRY (FF)

**Example: Solder Joint T-M qualification**

**Geometry A**

**Solder Joint (SJ)**

**Geometry B**

**Qualification requirement**

\[
\frac{N_{\text{use}}}{N_{\text{test}}} = \left( \frac{\Delta T_{\text{use}}}{\Delta T_{\text{test}}} \right)^n \left( \frac{f_{\text{use}}}{f_{\text{test}}} \right)^m \left[ \frac{1}{\frac{1}{\frac{1}{f_{\text{failure}}}} - \frac{1}{\frac{1}{f_{\text{test}}}}} \right]
\]

**Use Condition Risk**

<table>
<thead>
<tr>
<th>Requirement (A)</th>
<th>Requirement (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SJ damage (A) &gt;&gt; SJ damage (B)</td>
<td></td>
</tr>
</tbody>
</table>

**Not a function of FF**

**A function of FF**
ACCOUNTING FOR SYSTEM BOUNDARY CONDITIONS (BC)

Boundary conditions A

Boundary conditions B

Qualification requirement

$$\frac{N_{\text{use}}}{N_{\text{test}}} = \left( \frac{\Delta N_{\text{use}}}{\Delta N_{\text{test}}} \right)^n \left( \frac{f_{\text{use}}}{f_{\text{test}}} \right)^m \left( \frac{t_{\text{fail}}}{t_{\text{stress}}} \right)^{\frac{1}{n}} \left( \frac{r_{\text{strain}}}{r_{\text{stress}}} \right)^{\frac{1}{m}}$$

Use Condition Risk

Requirement (A) = Requirement (B)  SJ damage (A) ≠ SJ damage (B)

Not a function of BC  A function of BC

CHALLENGE
## ACCOUNTING FOR ACTUAL USE CONDITIONS

**Ex. T-M FLI qual**

<table>
<thead>
<tr>
<th>Use Condition</th>
<th>Empirical Acc. Model</th>
<th>Requirements ($N_{stress}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumed</td>
<td>$N_{use} / N_{stress} = (\Delta T_{use} / \Delta T_{stress})^n$</td>
<td>750 TCB</td>
</tr>
<tr>
<td>Measured UC</td>
<td>$N_{use} / N_{stress} = (\Delta T_{use} / \Delta T_{stress})^n$</td>
<td>It depends!!</td>
</tr>
</tbody>
</table>

**CHALLENGE**

- Extreme sensitivity to sampling rate!
<table>
<thead>
<tr>
<th>Challenges</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not account for FF (architecture, geometry, materials)</td>
<td>Defined in terms of applied stress, (like $\Delta T$)</td>
</tr>
<tr>
<td></td>
<td>Applied stress is often a very remote proxy for damage</td>
</tr>
<tr>
<td>Do not account for system boundary condition</td>
<td>$\text{Damage} = f(\text{applied stress, FF, system BC, materials...})$</td>
</tr>
<tr>
<td>Have difficulties accounting for measured UC</td>
<td>Every $\Delta T$ (both large and small) is considered to contribute to damage; more UC cycles always results in more damage and higher requirements</td>
</tr>
</tbody>
</table>
HOW TO GET CLOSER TO DAMAGE?
GETTING CLOSER TO THE PHYSICS

Example: Solder Joint (SJ) qual in temp.cycling (TC)

- From UC to requirements via fundamental (PoF) metrics
- Computational/Empirical methods necessary to leverage the PoF metric

Min Pei, Ru Han, Daeil Kwon, Alan Lucero, Vasu Vasudevan, Robert Kwasnick, Pravin Polasam, "Define Electrical Packing Temperature Cycling Requirement with Field Measured User Behavior Data”, ECTC 2013
<table>
<thead>
<tr>
<th>Approach</th>
<th>Metric</th>
<th>Use Conditions</th>
<th>Acceleration equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SBQ</strong> Standard (stress) based Qualification</td>
<td>Applied stress: (ex: ΔT)</td>
<td>Representative user</td>
<td>MTTF vs. ΔT</td>
</tr>
<tr>
<td><strong>KBQ</strong> Knowledge-based Qualification</td>
<td>PoF metric (ex: ISED)</td>
<td>Field measured users</td>
<td>MTTF vs. PoF metric</td>
</tr>
</tbody>
</table>

**KBQ**: Based on the PoF metrics and measured use conditions. Predictive modeling/simulation are necessary to overcome the limitations of empirical reliability models.
HOW **KBQ** OVERCOMES CHALLENGES OF **SBQ**
KBQ: REALISTIC ACCOUNT OF USE CONDITIONS

Empirical model: Damage Accumulation

PoF model: Damage Accumulation

Normalized Requirement

M. Pei, M. Vujosevic, S. Mukherjee, Knowledge Based requirement Calculation for server BGAs temperature cycling Qualification, InterPACK2017
**KBQ: ACCOUNTING FOR FF**

<table>
<thead>
<tr>
<th>FF</th>
<th>SBQ</th>
<th>KBQ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UC: 5cycles/day</td>
<td>UC: measured</td>
</tr>
<tr>
<td></td>
<td>1135 TCT</td>
<td>375 TCT</td>
</tr>
<tr>
<td>SBQ</td>
<td>1135 TCT</td>
<td>95 TCT</td>
</tr>
<tr>
<td>SBQ</td>
<td>1135 TCT</td>
<td>210 TCT</td>
</tr>
</tbody>
</table>

Geometry drives requirements
KBQ: ACCOUNTING FOR SYSTEM BC

No Adhesive | With Adhesive

Use Condition

Accel. test

SLI Qual. Requirements: KBQ vs. SBQ

SBQ: Requirements not dependent on adhesive

KBQ: Adhesive properties drive requirements

R. Han, M. Vujosevic, M. Pei, Physics Based Requirements for Qualification of BGA components in Temperature Cycling, InterPACK2015
HOW DO WE KNOW THAT THESE RESULTS MAKE SENSE?

**Validation #1**: Field data + End-of-Life (EOL) testing

**EOL data**: No SJ crack seen after 3.5 years.
**EOL testing**: No crack seen after more than 23,000 added power cycles.

BGA designed for 7 years life using empirical SBQ models

EOL experimental data indicate life > 40 years

SBQ: wrong conclusion about the performance in the field.

V. Vasudevan, et. al, ESTC2014
HOW DO WE KNOW THAT THESE RESULTS MAKE SENSE?

Validation #2: BGA Power cycling tests

SBQ: Empirical model projects life that is very different (in the case smaller) than the actual life
OUTLINE

- KBQ: Fundamental Building Blocks
- KBQ: Understanding Use conditions
- KBQ: Capturing the physics

- Implications and Examples

- Conclusions
KBQ IMPLICATIONS

EXAMPLES
**Enabling Design Optimization**

**NCTFs ~ [Qual. Requirement – Comp. Capability]**

**Qual. Requirement:**

- **NCTF definition:** KBQ: Potential to reduce component size
- **Implications on cost and board space**

**Impact of KBQ on package size reduction (UC+ physics metrics + modeling)**

**Standards Based Qual**

- Empirical Based
- KBQ
- Physics + Modeling

**M. Vujosevic, ESCTC2014**
PROTECTING CUSTOMERS

SLI (Second Level Interconnects)

TMI (Through Mold Interconnects)

Memory

KBQ: TC Requirements (normalized)

SLI

TMI

SLI: KBQ > SBQ -> SBQ not conservative!!!! Component passes SBQ but is likely to fail in the field

KBQ protects customers!!
ENABLING NEW PROCESS

SLI: (Second Level Interconnects)
TMI: (Through Mold Interconnects)

Challenging SMT

SBQ req: too conservative -> driving design choices that can limit SMT optimization

KBQ can help process/assembly optimization of new architectures
ENABLING NEW TECHNOLOGIES

LOW TEMPERATURE SOLDER (LTS) PASTE: path for reduced yield loss in SMT

TC Margin Loss ~ 50% in component qual tests
SBQ requirements not met

<table>
<thead>
<tr>
<th>Risk Mitigation</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add sacrificial solder joints</td>
<td>Increase of package size</td>
</tr>
<tr>
<td>Improve paste ductility</td>
<td>Rel still not on par with SAC (new paste materials being developed/evaluated)</td>
</tr>
<tr>
<td>Add underfill</td>
<td>Cost increase + rework implications</td>
</tr>
<tr>
<td>Reduce conservatism in SBQ</td>
<td>KBQ requirements likely to be met</td>
</tr>
</tbody>
</table>

SBQ: Requirements NOT paste material dependent. Many LTS formulations do not meet SBQ
KBQ: Requirements are paste material dependent. LTS paste likely to meet KBQ for BGAs

KBQ reduces conservatism of SBQ and can enable new technologies

M. Vujosevic, SMTAI2016
KBQ: ADDITIONAL EXAMPLES

• KBQ for BGA Shock
• KBQ for Socket Fretting
KBQ FOR BGA SHOCK:
DEFINITION OF REQUIREMENTS

System Level / Use Condition Demand ($G_{\text{system}}$)

Component level Requirement ($G$)

SJ Damage Metric: STRESS

From use conditions to requirements via POF metric

<table>
<thead>
<tr>
<th>Approach</th>
<th>Damage Metric</th>
<th>User Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBQ</td>
<td>Board strain, or Shock table accel. G or Top package accel. G</td>
<td>Legacy value</td>
</tr>
<tr>
<td>KBQ</td>
<td>Solder joint stress</td>
<td>Field measured users</td>
</tr>
</tbody>
</table>

M. Pei, G. Arakere, M. Vujosevic, “Knowledge Based Qualification Methodology to Evaluate Shock Induced Risks in BGA Components”, ASME InterPACK2017
KBQ FOR SOCKET FRETTING: DEFINITION OF REQUIREMENTS

Use Condition Demand (System $G_{RMS}$)

Fretting PoF metric: Socket Pin Sliding Distance

Component level Requirement ($Grms$)

From use conditions to requirements via POF metric

<table>
<thead>
<tr>
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<th>Damage Metric</th>
<th>User Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBQ</td>
<td>Energy in $Grms$</td>
<td>Legacy value</td>
</tr>
<tr>
<td>KBQ</td>
<td>Pin Sliding Distance</td>
<td>Field measured users</td>
</tr>
</tbody>
</table>

CONCLUSIONS
Standards are necessary but not sufficient. The new reliability frontier is knowledge based. Use of contemporary tools of engineering is needed. Standards need to further evolve to meet the challenges of our time.
Thank you!