A Manufacturer’s Perspective on System Reliability for SSL products

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Topics

Where are we now with reliability?

What can we do better?
  
  Speed it up, with accelerated testing
  Make it more cost effective, by designing optimally
  
  Avoid underdesign → premature failure
  Avoid overdesign → cost higher than needed
Reliability - Definition

Reliability - the probability that the equipment will perform its **intended function**, **under stated conditions**, for a **specified period of time** without failures

- What function should the equipment perform?  
  (E.g.: give light, dim, change color, …)
- Under what **application (use) conditions** should the equipment function?  
  (e.g.: temp., humidity, vibration, …)
- How long should the equipment last?  
  (e.g.: Technical or economical lifetime)
Lighting Transformation

**Conventional**
- Operating lifetime is short
- Product lifetime in the market is long

**SSL**
- Operating lifetime is long
- Product lifetime in the market is short

So, we have to do a lot of work to ensure long lifetime, for a product we are only going to sell for a short time.

More testing/product!
More products to test!
## Identified Critical Failure Modes

<table>
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<th>Level</th>
<th>Identified Failure Modes</th>
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| 0: Bare Die          | • LED catastrophic failure  
                          • Lumen depreciation (several causes)  
                          • Degradation of active region / ohmic contact  
                          • Electro-migration causing dislocations  
                          • Diffusion of metal atoms to the active region  
                          • Current crowding (uneven current distribution)  
                          • Doping related failures                                      |
| 1: Packaged LED      | • Yellowing of packaging materials (degradation/aging)  
                          • Electrostatic discharge (ESD)  
                          • Interconnect failure (solder or die-attach)                                     |
| 2: LED on substrate  | • Cracks (f.e. in the ceramic)  
                          • Solder fatigue  
                          • PCB metallization problem  
                          • Short (f.e. due to solder bridging)                                       |
| 3: LED module        | • Casing cracks  
                          • Driver failures  
                          • Optic degradation (browning, cracks, reflection change)  
                          • ESD failures                                      |
| 4: Luminaire         | • Fractures (f.e. due to vibrations)  
                          • Moisture related failures (f.e. popcorning)  
                          • Corrosion due to water ingression  
                          • Deposition of outgassing material on the optics                              |
| 5: Lighting system   | • Software failures  
                          • Electrical compatibility issues  
                          • Installation & commissioning issues                                     |

Each FM has a certain ppm level, which we need to understand, minimize or solve & understand using reliability lifetime tests and analytical / numerical models.
SSL products have 5 key-components

1. LED engine
2. Optics
3. Electronics
4. Cooling system
5. Mechanical construction
Experience-Based Approaches: Derating

• Basic principle: Same as your mother and father told you as a child: Treat your toys gently and they will last longer.

• Component manufacturers generally specify maximum temperatures, currents, etc → but life will be reduced.

• How gently do you have to treat it?
  • Depends on how long you want it to last.

• Based on experience with a component, we can come up with derating curves.

• But what if a new component comes along or a change is made to an existing component? Mature change management is needed.
Experience-Based Approaches: Derating

• Treat component A gently via derating
• Treat component B gently via derating

• But somehow, there is a problem when A and B are integrated. Interactions between the components (not foreseen) may create new failure mechanisms.

• There may be 100-200 components in an LED lamp/luminaire. Plenty of potential for unexpected interactions and failures.
Experience-Based Approaches: Stress Testing

• During development, put products through a battery of tests, to see if they survive.
  • Extreme temperatures
  • High/low line voltage
  • Extreme humidity
  • Vibration
  • Different operating conditions (eg. On/off, vary CCT, dimming,…)
  • Chemical exposure (e.g. salt spray)

• But correlations between test results and product lifetime are experience-based “rules of thumb”.

• What if something changes?
System Reliability

• In principle: Component failure ≠ System failure
• Each component in a system exhibits its own failure behavior
• This component failure behavior needs to be captured by:
  – Experiments by using at least 3 accelerated testing conditions
  – Numerical / analytical models that describe the Physics of Failure
• Interactions between the components need to be captured by:
  – Testing sub-systems
  – Testing the total system
  – By accelerating environmental user conditions in a physically correct manner
Acceleration

Experiment to assess the endurance of devices by “accelerating” shipment, mounting & application conditions

Stress Test (test conditions)  ↔  Environmental Test (field application)

Acceleration Factor = time to failure in application / time to failure in test
Examples

Humidity Damp Heat

Sleeve tests

Highly Accelerated Life Test

Operational Tests
The risk of Blind Acceleration

21 days 37°C

3 minutes 140°C
Philips Approach for Reliability

• Combination of:
  – Derating rules (individual component basis)
  – Stress testing (many stresses)
    • Acceptable limits are set based on experience
  – Accelerated testing on sub-system level
    • Acceptable limits are set, based on understanding of physics of failure
      and acceleration factors
    • But there are many failure mechanisms. We have acceleration factors
      for our top 5 failure modes.
  – Verification testing on system level
  – System Reliability is based on Modeling \( \rightarrow \text{Predicted lifetime based on projected field call rates.} \)
Needs

• Fundamental knowledge and industrial practices to understand the failure mechanisms. Both on component and system level.

• Fast, reliable and cost effective reliability qualification methods / procedures that allow coverage of the total product warranty period

• Acceleration factors (for each failure mechanism) to translate the accelerated test results to actual user conditions

• Multi-location efforts to determine the acceleration factors for each failure mechanism. Cooperate to share best practices and data.