Power Supply Reliability

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VP of Quality
Topics

• Reliability
  – 31 Critical items
• Summary
• Questions & Answers
• References
Design/Manufacturing for High Reliability

1. Power supply reliability must be designed in
   - Rigorous spec review up front is key to process

2. Causes of high return rates
   - Inadequate or poor product specs
     • Example – Returns traced to an unspecified, untested switching parameter
   - Inadequate validation of proper performance in end application
3. Use successful topologies with proven components\textsuperscript{15}

4. Design process must be highly structured, with design reviews for reliability, manufacturability, and testability (DFR\textsuperscript{4}, DFM, DFT)
   ➢ No amount of good manufacturing can fix a poor design\textsuperscript{9}

5. Component Derating
   ➢ Each category defines allowable thermal and electrical stresses

6. Designing for safety increases reliability

7. Transient protection at input\textsuperscript{4}

8. Soft-start circuit to minimize turn-on stresses\textsuperscript{4}

9. Current limit for output protection
10. Use zero-crossing circuitry to minimize switching losses

11. Design PCB & packaging for best thermal transfer, along with optimal layout for minimizing circuit noise, and best EMC performance

12. PCB heat flow should be directed towards chassis mount or heat dissipating surface, with path as short as possible
   - Surfaces / finishes selected to provide low thermal resistance.

13. Semiconductor junction temperatures should be as cool as possible
   - Per MIL STD 883B, 25ºCΔT corresponds to >10Δλ
   - As device temperature increases, failure rate goes up
Reliability – 31 Critical Elements

Semiconductor Failure Rate vs. Temp.$^{10}$
14. Verify proper loop stability under all variations

15. Use of FET avalanche rating for normal circuit operation may result in FET failures. It’s better to use the FET standard ratings for normal circuit operation.

16. Minimize use of electrolytic capacitors
Reliability – 31 Critical Elements

Typical Leaded Electrolytic Capacitors\textsuperscript{14}
17. Use only sealed 105°C minimum electrolytic capacitors
   
   **Store between 5°C and 25°C**
   
   - Storage above 40°C may increase leakage current³
   - Storage below 0°C may freeze electrolyte, causing bulged case
   - Run cool - every 10°C rise in ambient reduces life by 50%.⁵
   - Specify epoxy end seals to prevent entry of contaminants, esp. when there is a cleaning process⁶
Reliability – 31 Critical Elements

Cap Failure Rate vs. Temp.\textsuperscript{5}

![Graph showing the relationship between core temperature of a capacitor and failure rate. The x-axis represents core temperature in °C ranging from 20 to 110, and the y-axis represents failure rate in failures/10^6 hours, ranging from 0.001 to 10. The graph includes two lines: one solid and one dashed, indicating different failure rates.]
18. Use generous design margins to compensate for drop of opto-isolator CTR (current transfer ratio) over time.
   - Increased LED (light emitting diode) current and/or increased temperature will accelerate CTR degradation.

\[
\text{CTR} = \frac{I_C}{I_F}
\]
Typical CTR Degradation Trend

- Duration, Hours
- CTR Degradation
- %

IF=1mA, 60°C
IF=7mA, 60°C
IF=10mA, 60°C

IF=1mA, 100°C
IF=7mA, 100°C
IF=10mA, 100°C

20. Temperature reduction techniques for transformers
   - Low loss core material
   - Litz wire / foil for reduced coil heating
Typical Thermal Aging

Where

\[ Q = \frac{X_L}{R_S} \]

- \( Q \) = Quality Factor
- \( X_L \) = Inductive Reactance
- \( R_S \) = Series Resistance

%Q vs Age Time

100 Turns, 100kHz, 1G
21. Litz wire can be used instead of standard wire to reduce coil heating in transformers

- Made from multiple, individually insulated strands, twisted together for reduced skin effect and lower effective AC resistance\(^{17}\)
  - Skin effect - AC electricity tends to flow on the conductor surface\(^{18}\)
  - Special soldering process required

Type 1 Litz Wire - Round, single twisting operation with optional outer insulation
22. Avoid nylon-coated wire in magnetics assemblies
   - Some nylon-coated wire is hygroscopic, causing dielectric breakdown problems in high humidity

23. Keep solder flux off magnetic wire during assembly
   - High temp exposure will activate flux, degrading wire insulation
   - Long term exposure to active flux may lead to wire failure
   - No-clean flux preferable for magnetics assembly

24. When cores must be glued, process development / control is critical
   - Qualify glue over extended temperature range, with MSL (moisture sensitivity level) testing
   - Core cleanliness critical for joint integrity and gap control
   - Control of glue storage and shelf life is key for joint integrity
   - Face joints are more reliable than lap joints
Glue joints for magnetic cores
## Qualification of Transformer Glue

### Glue Evaluation

<table>
<thead>
<tr>
<th>Unit#</th>
<th>Initial L</th>
<th>After T/C</th>
<th>Low Reflow</th>
<th>High Reflow</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68.8</td>
<td>64.6</td>
<td>66.0</td>
<td>68.2</td>
<td>1.95</td>
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<tr>
<td>2</td>
<td>69.0</td>
<td>67.0</td>
<td>68.6</td>
<td>69.2</td>
<td>1.00</td>
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<tr>
<td>3</td>
<td>71.8</td>
<td>64.4</td>
<td>69.8</td>
<td>69.6</td>
<td>3.16</td>
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<tr>
<td>4</td>
<td>62.8</td>
<td>61.4</td>
<td>63.2</td>
<td>64.0</td>
<td>1.09</td>
</tr>
<tr>
<td>5</td>
<td>64.9</td>
<td>62.2</td>
<td>64.4</td>
<td>64.8</td>
<td>1.27</td>
</tr>
<tr>
<td>6</td>
<td>69.6</td>
<td>63.2</td>
<td>68.8</td>
<td>69.0</td>
<td>2.99</td>
</tr>
<tr>
<td>7</td>
<td>65.6</td>
<td>64.0</td>
<td>65.4</td>
<td>66.4</td>
<td>1.00</td>
</tr>
<tr>
<td>8</td>
<td>66.4</td>
<td>60.2</td>
<td>65.2</td>
<td>65.6</td>
<td>2.81</td>
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<tr>
<td>9</td>
<td>68.8</td>
<td>66.2</td>
<td>68.6</td>
<td>69.4</td>
<td>1.41</td>
</tr>
<tr>
<td>10</td>
<td>69.4</td>
<td>63.6</td>
<td>69.0</td>
<td>69.4</td>
<td>2.84</td>
</tr>
</tbody>
</table>

| Std. Dev. | 2.70 | 2.07 | 2.31 | 2.15 | 1.95 |

### Graph

The graph illustrates the variation of inductance for different conditions:
- **Initial L**
- **After T/C**
- **Low Reflow**
- **High Reflow**

- **Min Inductance** (Red)
- **Max Inductance** (Green)

The data shows a consistent range of inductance variation across different units and conditions, indicating the stability and reliability of the transformer glue.
25. Use “lessons learned” from earlier problems found
   - Example: Cracked SMT MLCC capacitors

   - Parameters affecting problem:
     - Singulation Process
     - PCB Flexibility
     - Pad Geometry
     - Dielectric
     - Body Size
     - Reflow Profile
     - Mechanical Parts
     - Capacitor Orientation
     - Solder Fillet Control
     - Proper Rework Process
Cracked SMT MLCC Capacitor
Reliability – 31 Critical Elements

Panelized PCBs
Cracked Capacitor due to Board Flexure

References:
1. [Cracked Capacitor due to Board Flexure](#)
Reliability – 31 Critical Elements

SMT MLCC Capacitors with Reduced Pads
**Capacitor Dielectric vs. Young’s Modulus of Elasticity**

<table>
<thead>
<tr>
<th>Dielectric Material</th>
<th>Young’s Modulus (Kgf/Cm²)</th>
<th>Young’s Modulus (MegaPascalsMpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0G</td>
<td>1.2 ~ 1.3 × 10⁶</td>
<td>1.3 × 10⁵</td>
</tr>
<tr>
<td>X7R</td>
<td>1.1 ~ 1.2 × 10⁶</td>
<td>1.1 × 10⁵</td>
</tr>
<tr>
<td>Z5U &amp; Y5V</td>
<td>0.9 ~ 1.0 × 10⁶</td>
<td>0.9 × 10⁵</td>
</tr>
</tbody>
</table>
Reliability – 31 Critical Elements

Typical Reflow Profile

<table>
<thead>
<tr>
<th>Company</th>
<th>CD Technologies</th>
<th>Process</th>
<th>Omniflow 7</th>
<th>Printed</th>
</tr>
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<tbody>
<tr>
<td>Site</td>
<td>CD Tucson, AZ</td>
<td>Product</td>
<td>Line Speed</td>
<td>04/21/1999</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
</tr>
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<tbody>
<tr>
<td>Onload</td>
</tr>
<tr>
<td>Preheat</td>
</tr>
<tr>
<td>Zone 2</td>
</tr>
<tr>
<td>Zone 3</td>
</tr>
<tr>
<td>Zone 4</td>
</tr>
<tr>
<td>Zone 5</td>
</tr>
<tr>
<td>Zone 6</td>
</tr>
<tr>
<td>Reflow Cooldown</td>
</tr>
<tr>
<td>Offload</td>
</tr>
<tr>
<td>End</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Speed</th>
<th>Onload</th>
<th>Preheat</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
<th>Zone 6</th>
<th>Reflow</th>
<th>Cooldown</th>
<th>Offload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>0</td>
<td>90</td>
<td>115</td>
<td>150</td>
<td>150</td>
<td>170</td>
<td>195</td>
<td>250</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lower</td>
<td>0</td>
<td>90</td>
<td>115</td>
<td>150</td>
<td>150</td>
<td>170</td>
<td>195</td>
<td>250</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Excessive Solder vs. Adequate Solder
26. Electromechanical Parts and Packaging Strongly Affects Reliability

- Sockets / Connectors / Fasteners will reduce reliability. Eliminate where possible.

- Product construction and shipping packaging must be robust, to withstand abuse in shipment.
  - Parts soldered to PCB should be flush mounted if possible
  - Large parts soldered to PCB should have good mechanical support
  - PCB should have proper support under large parts
27. Perform comprehensive design verification test (DVT – testing to specified limits on all parameters)

28. Qualification testing: Test beyond limits to identify margins\(^\text{15}\), including static / dynamic thermal stresses, 6 axis vibration, power line disturbances, ESD (Electrostatic Discharge), and high-pot breakdown. This can be done through the HALT (Highly Accelerated Life Testing)\(^\text{6}\) process
   
   - The design must have margin above the stresses it will see in manufacturing and the field\(^\text{9}\)

29. Conduct life testing, with power cycling\(^\text{15}\), load variation, and input voltage variation, with 100K device hours. Complete FA (Failure Analysis) / CA (Corrective Action) on all failures
“Bath Tub” Curve of Product Life Cycle $^{12,15,16}$
30. Conduct MRV (manufacturing readiness verification), and ensure that statistical process controls are in place, with FPY (First Pass Yield) tracking, and maximized use of automation.\(^{15}\)

   - FPY = Product of all separate test yield percentages

31. As FPY approaches 99%, individual yields approach and exceed 99.99% +, the product design and process become centered and field return rate drops
Reliability – 31 Critical Elements

First Pass Yields

<table>
<thead>
<tr>
<th>Control Point</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
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<tbody>
<tr>
<td>Bd. Level Test</td>
<td>98.23</td>
<td>96.86</td>
<td>97.27</td>
<td>97.09</td>
<td>94.5</td>
<td>96.88</td>
<td>98.39</td>
<td>98.75</td>
<td>98.75</td>
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<tr>
<td>1st Test</td>
<td>92.2</td>
<td>93.71</td>
<td>87.52</td>
<td>91.97</td>
<td>92.02</td>
<td>93.53</td>
<td>96.17</td>
<td>97.28</td>
<td>98.39</td>
</tr>
<tr>
<td>Hi-Pot</td>
<td>98.83</td>
<td>99.72</td>
<td>99.61</td>
<td>99.07</td>
<td>98.74</td>
<td>96.92</td>
<td>98.9</td>
<td>99.62</td>
<td>99.64</td>
</tr>
<tr>
<td>Final Test</td>
<td>94.77</td>
<td>97.19</td>
<td>96.12</td>
<td>98.23</td>
<td>98.48</td>
<td>97.95</td>
<td>98.95</td>
<td>99.23</td>
<td>99.84</td>
</tr>
<tr>
<td>First Pass Yield</td>
<td>83.37%</td>
<td>86.27%</td>
<td>80.26%</td>
<td>85.98%</td>
<td>83.47%</td>
<td>85.25%</td>
<td>91.61%</td>
<td>94.66%</td>
<td>96.32%</td>
</tr>
</tbody>
</table>

Monthly Yield Summary % YIELD
Summary

• C&D Technologies Overview

• Quality

• Reliability
  – 31 Critical items
Questions and Answers
References

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