Development and Package Characterization of Advance Leadless Lead-frame Package

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Overview

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- Evolution of leadless lead frame package
- GQFN process flow
- Advantages of GQFN
- Manufacturing Challenges
- Package analysis
  - Thermal performance
  - Electrical performance
- Board level reliability
  - Drop test
  - Temperature cycling on board
- Conclusion
GQFN Introduction

UTAC’s new generation of leadframe package design - Grid Array QFN (GQFN)

Increasing demand for:
- Higher functionality
- Package with smaller footprint
- Higher I/O density
- High performance
- Cost competitive packages

GQFN Package Characteristic:
- Lead frame material which allows traces to be routed through etching process
- Higher I/O density compared to QFN
- High design flexibility (BGA/LGA)
Development in Leadless Lead-frame Package

Quad Flat No-lead (QFN) package → Dual row QFN (DQFN) package → Thermal Leadless Array (TLA) package

Grid Array QFN (GQFN) package → Hi-Density Leadless Array (HLA) package

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Evolution of QFN Package in UTAC

Package Form Factor

QFN

QFN
Fine Pitch
0.4/ 0.35/0.3

LLGA

Dual Row
QFN

TLA

HLA

GQFN

Increasing I/O or Miniaturization

Since 1999
2009
2010
2011
2012
2013
2014

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GQFN Process Flow

Top View: Single unit on bare leadframe
- Cu Base
- Cu Trace
- PPF Plating

Bottom View: Single unit on bare leadframe
- Actual Terminal Plating

X-Ray View (Showing top & Bottom)
- Copper Etched out

Screen print on back die and D/A on leadframe
- Mold

2nd Mold (Insulation mold)
- Etching Process

Bottom View after 1st mold
- 1st Mold (Top Mold)

W/B
Process Flow Comparison

**HLA**
- Soldermask
- From Front-of-Line process
  - Encapsulant
  - Etch Back
- Solder Mask Process Step
  - Pre Treatment
  - Solder Mask printing
  - Vacuum & Cure
  - Solder Mask Exposure
  - Solder Mask Develop
  - Post Cure
- EOL

**GQFN**
- Mold Compound
- From Front-of-Line process
  - Encapsulant
  - Etch Back
  - Insulation Mold (New Process)
  - Post Cure
- EOL

Insulation Mold Process have lesser step than Solder Mask Process
Advantages of GQFN:
Smaller Footprint & Higher I/O number

Smaller footprint:

- QFN @0.5 mm Pitch
  - 56L 8x8 mm QFN
  - PCB Area Ratio = 1.0

- TLA @0.5 mm Pitch
  - 64L 6x6 mm TLA
  - PCB Area Ratio = 0.56

- GQFN @0.5 mm Pitch
  - 68L 5x5 mm GQFN
  - PCB Area Ratio = 0.39

Higher I/O number:

- 44L 5x5 mm QFN
- 100L 5x5 mm GQFN

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GQFN vs FBGA Thermal Performance – Test Conditions

Test Conditions

JEDEC Still Air Chamber

- Test Fixture
- Support Base
- Ambient: 25 °C

JEDEC PCB

Package

JEDEC Forced Air Chamber

- Wind Flow 1-3m/s
- Support for PCB
- Ambien: 25 °C

Note: Theta JA as per JESD51-2A, and Forced air wind tunnel for Theta JMA as per JESD51-6
GQFN vs FBGA Thermal Performance – Package Details

Notes:

1. Package size (mm)  
   - GQFN: 5.0 x 5.0 x 0.35  
   - FBGA: 5.0 x 5.0 x 0.53

2. Die size (mm)  
   - 2.9 x 2.65 x 0.1

3. Substrate thickness (mm)  
   - 0.13 (with 2L substrate trace)  
   - 0.015mm trace thickness

4. PCB: JEDEC 2S2P (4L) per JESD 51-7

Package structure assumptions:
- Substrate based vs Leadframe based (equivalent Cu%) on traces
# GQFN vs FBGA Thermal Performance – Package options for thermal study

## Thermal resistance vs Air speed

<table>
<thead>
<tr>
<th>Thermal resistance</th>
<th>Air speed</th>
<th>Package Type</th>
<th>FBGA 5x5mm</th>
<th>xGQFN 5x5mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theta JA (°C/W)</td>
<td>0</td>
<td>Leg 1 (control)</td>
<td>61.4</td>
<td>53.7</td>
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<tr>
<td></td>
<td></td>
<td>Leg 2</td>
<td>53.7</td>
<td>46.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leg 3</td>
<td>46.3</td>
<td>34.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leg 4</td>
<td>34.3</td>
<td>22.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leg 5</td>
<td>30.9</td>
<td>21.8</td>
</tr>
<tr>
<td>Theta JMA (°C/W)</td>
<td>1</td>
<td>Leg 1 (control)</td>
<td>52.6</td>
<td>46.2</td>
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<tr>
<td></td>
<td></td>
<td>Leg 2</td>
<td>46.2</td>
<td>38.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leg 3</td>
<td>38.7</td>
<td>35.6</td>
</tr>
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<td></td>
<td></td>
<td>Leg 4</td>
<td>35.6</td>
<td>23.7</td>
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<td>Leg 5</td>
<td>33.3</td>
<td>21.8</td>
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<tr>
<td></td>
<td>2</td>
<td>Leg 1 (control)</td>
<td>51.0</td>
<td>44.7</td>
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<tr>
<td></td>
<td></td>
<td>Leg 2</td>
<td>44.7</td>
<td>37.3</td>
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<tr>
<td></td>
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<td>Leg 3</td>
<td>37.3</td>
<td>34.2</td>
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<tr>
<td></td>
<td></td>
<td>Leg 4</td>
<td>34.2</td>
<td>22.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Leg 1 (control)</td>
<td>49.9</td>
<td>43.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leg 2</td>
<td>43.7</td>
<td>36.3</td>
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<tr>
<td></td>
<td></td>
<td>Leg 3</td>
<td>36.3</td>
<td>33.3</td>
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</tbody>
</table>

## Package Design and Assumptions

<table>
<thead>
<tr>
<th>Leg#</th>
<th>Package design and assumptions</th>
<th>DA thermal conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg 1</td>
<td>BGA 5x5mm (control)</td>
<td>1.5 W/mK</td>
</tr>
<tr>
<td>Leg 2</td>
<td>GQFN 5x5mm using DAF</td>
<td>0.3 W/mK</td>
</tr>
<tr>
<td>Leg 3</td>
<td>GQFN 5x5mm using HT die attach</td>
<td>4 W/mK</td>
</tr>
<tr>
<td>Leg 4</td>
<td>GQFN 5x5mm using HT die attach with epad</td>
<td>4 W/mK</td>
</tr>
<tr>
<td>Leg 5</td>
<td>GQFN 5x5mm using HT die attach with epad and PCB vias</td>
<td>4 W/mK</td>
</tr>
</tbody>
</table>

## Improvement in Theta JA:
- 12.5% improvement with xGQFN using DAF die attach (0.3 W/mK)
- 24.6% improvement with xGQFN using HT die attach (4 W/mK)
- 30% improvement with xGQFN with exposed pad
- 49.7% improvement with xGQFN with exposed pad on PCB with thermal vias
GQFN vs FBGA Thermal Performance
(die attach and exposed pad study)

Significant improved thermal performance using GQFN.
Due to direct conduction to the PCB via leadframe and solder.
Heat spreading effect of the die paddle, while for BGA package the heat is transferred from substrate layer-1 to layer-2 through limited substrate vias.
Potential to improve thermal performance more than 40% using GQFN with exposed pad and PCB vias.
GQFN vs FBGA Electrical Performance

Both packages were simulated using Ansoft Q3d Extractor and ADS (Advance Design System)

A parasitic extraction was performed to obtain the RLC values. (resistance, inductance and capacitance) to compare its package performance at low frequency.

S-parameter extraction conducted to check package performance at higher frequency

<table>
<thead>
<tr>
<th>Item</th>
<th>GQFN</th>
<th>fBGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leadframe/Substrate Thickness (mm)</td>
<td>0.1</td>
<td>0.13</td>
</tr>
<tr>
<td>Wire Type/Loop height</td>
<td>25um Au/0.1mm</td>
<td></td>
</tr>
<tr>
<td>Solder Ball (mm)</td>
<td>0.1</td>
<td>0.17</td>
</tr>
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</table>
No significant difference between the two packages.

The electrical performance of GQFN package is as comparable to FBGA package at low frequency.

**RLC Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Resistance (Ohm)</th>
<th>Inductance (nH)</th>
<th>Capacitance (pF)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GQFN</strong></td>
<td>0.052</td>
<td>0.658</td>
<td>0.143</td>
</tr>
<tr>
<td><strong>fBGA</strong></td>
<td>0.055</td>
<td>0.757</td>
<td>0.135</td>
</tr>
</tbody>
</table>
A frequency sweep was performed on the longest span of a signal for each package.

The GQFN package will have a good electrical performance up to 3.9GHz that is higher than FBGA package which is limited at 2.85GHz. (Return Loss)

Difference between the two packages can be seen and the GQFN package is better than FBGA package as FBGA package's electrical performance deteriorate 1GHz lower than GQFN package. (Insertion loss)

*Note: Conditions used were -1dB limit for insertion Loss and -15dB for the return Loss.
Board Level Reliability – Drop Test

GQFN 5x5mm packages were mounted on 132x77x1.0mm 8-layers board which was designed to form an integrated daisy-chain with packages.

JESD22-B110: 1500 Gs, 0.5 millisecond duration, half-sine pulse

Package has shown excellent dropped performance with first failure at 470 cycles and characteristic life of 950 cycles.
Board Level Reliability – TCoB

GQFN 5x5mm packages were attached to 200x150mm board and subjected to accelerated life tests to determine their second level reliability.

GQFN 5x5mm had excellent TCoB performance with first failure at 2,680 cycles and characteristic life of 4,600 cycles.
Summary of reliability test results

<table>
<thead>
<tr>
<th>Test</th>
<th>Standard</th>
<th>Conditions</th>
<th>xGQFN Package 5x5mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Sensitivity Level Test</td>
<td>J-STD-020D.1, MSL1</td>
<td>168hrs, 85C/85% RH</td>
<td>Passed</td>
</tr>
<tr>
<td>Unbiased Temp/Humidity (uHAST)</td>
<td>JESD22-A118</td>
<td>130C/85% RH, 96Hrs/192Hrs</td>
<td>96 Hrs-Passed 192Hrs-Passed</td>
</tr>
<tr>
<td>Temperature Cycle</td>
<td>JESD22-A104, TC Cond C</td>
<td>-65C to 150C, 500/1000cyc</td>
<td>500cyc-Passed 1000cyc-Passed</td>
</tr>
<tr>
<td>High Temperature Storage</td>
<td>JESD22-A103 &amp; A113</td>
<td>150C, 500hrs/1000hrs</td>
<td>500Hrs-Passed 1000Hrs-Passed</td>
</tr>
</tbody>
</table>

Experimental moisture sensitivity level (MSL) test and accelerated moisture resistance –unbiased HAST (uHAST) were performed on the same xGQFN 5x5mm 79L package. Passed MSL 1, uHAST, temperature cycle and HTS at test conditions shown above.
Conclusion

GQFN is an innovative product which allows breakthrough in addressing QFN I/O limitation and provides form factor miniaturization advantages over QFN packages.

Highlights of the advantages of this package are:

- Form factor miniaturization for QFN packages
- Address complicated bonding layout for dual/multi row leadless configuration
- Good thermal performance
- Superior electrical performance
- Pass all package and board level reliability requirements in accordance with IPC/JEDEC standards.
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