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<td>✓ Board PBC &amp; Heat spreader</td>
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Executive Summary

- A smartphone contains several components that generate heat and other components sensitive to heat; to maintain acceptable temperature levels in these small handheld devices, manufacturers propose different solutions which require high performance and design constraints.

- To complement Yole Développement’s Thermal Management in Smartphones report, System Plus Consulting has conducted a comparative technology review to provide insights into the assembling structure and thermal management technology of 10 flagship smartphones from leading suppliers: Apple, Samsung, Huawei, LG and Xiaomi.

- In this report, we highlight the differences and the innovations in the thermal management solutions chosen by the end-user OEMs.

- Whereas some OEMs use standard solutions such as heat spreaders of metal frames, others choose to consider more complex structures such as heat pipes.

- Moreover, as the processor is one of the most important heat sources, we have seen how the PCB design has changed to improve thermal dissipation and how the packaging of the processor itself has evolved to solve thermal problems caused by miniaturization and efficiency increase. Located close to the battery and the DRAM chip on the main board, the application processors are packaged using different PoP technologies. Some AP providers, like HiSilicon or Samsung, use conventional PoP with embedded land-side capacitors; others, like Apple or Qualcomm, use innovative technologies like fan-out PoP or embedded die packaging with advanced PCB substrates.

- This report includes multiple comparisons based on physical analyses of the latest flagship smartphones. It offers the unique possibility of seeing thermal management technology evolution, tracked by manufacturer.
Why thermal management in smartphones?

- Thermal management for modern electronic systems can follow two fundamental paths: one concentrates design efforts towards low power/high efficiency electronic circuits/components, the other implies, where the previous one reaches its limits, optimizing thermal transfer in the entire system at chip level, package level, and PCB/assembly level.

- Those technological evolutions could be seen in smartphones because of the big market share. Big market share and small devices sizes push the telephone manufacturers to improve the processor performances (low power/high efficiency) and/or optimize thermal transfer in the complete smartphone system.

- Device manufacturers are interested in following these evolutions because they will be then integrated in other electronic systems.
Samsung, Apple and Huawei were the leading smartphone suppliers in 2016.

![2016 smartphone market in M units sold, breakdown by supplier](image)

**Market share of leading smartphone suppliers in 2016 by number of smartphones sold.**

*Yole Développement*
Thermal Management Market

- TM component value relative to total BoM seems to be extremely low, but considering the huge number of smartphones sold per year, TM components represent important revenue for suppliers.
- Despite the small share of thermal management components in total smartphone value, their role is crucial to avoid overheating issues which are undesirable for customers.

![2016 smartphone BOM breakdown](image)

Source: Yole Développement
Analysed Telephones

- Ten references of telephones have been analyzed.

<table>
<thead>
<tr>
<th>End-users OEM</th>
<th>Device</th>
<th>Smartphones sold (2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>iPhone 6S Plus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>iPhone 7 Plus</td>
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<td></td>
<td>iPhone 8</td>
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<td></td>
<td>iPhone X</td>
<td></td>
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<tr>
<td>Samsung</td>
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<td>287.2 MUnit</td>
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<tr>
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<td>Galaxy S8</td>
<td></td>
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<tr>
<td>Huawei</td>
<td>P9</td>
<td>143.6 MUnit</td>
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<td></td>
<td>Mate 9</td>
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<tr>
<td>LG</td>
<td>G6</td>
<td>43.1 MUnit</td>
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<tr>
<td>Xiaomi</td>
<td>Mi5</td>
<td>86.2 MUnit</td>
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### Analysed Processor Packaging

<table>
<thead>
<tr>
<th>End-users OEM</th>
<th>Device Integration</th>
<th>Component provider</th>
<th>Packaging Assembly &amp; test Services</th>
<th>Packaging Technology</th>
<th>Footprint (mm²)</th>
<th>Die Manufacturer</th>
<th>Die Area (mm²)</th>
<th>Die thickness</th>
<th>I/O Number</th>
<th>PCB/RDL Minimum L/S (µm)</th>
<th>Pitch (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>iPhone 6S</td>
<td>Apple</td>
<td>TSMC</td>
<td>FC-PoP</td>
<td>14.8 x 14.5 (214)</td>
<td>Samsung</td>
<td></td>
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<tr>
<td></td>
<td>iPhone 7</td>
<td>Apple</td>
<td>TSMC</td>
<td>inFO</td>
<td>15 x 15 (225)</td>
<td>TSMC</td>
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<tr>
<td></td>
<td>iPhone 8</td>
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<td>TSMC</td>
<td>inFO</td>
<td>15 x 14 (210)</td>
<td>TSMC</td>
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<td></td>
<td>iPhone X</td>
<td>Samsung</td>
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<td>15.5 x 14.5 (225)</td>
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<td>Samsung</td>
<td>Galaxy S7</td>
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<td>P9</td>
<td>HiSilicon</td>
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<td>TSMC</td>
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Why telephones get hot?

There are different reasons for overheating of telephones: these can be related to the design, the construction itself, the utilization mode and the environment.

**Smartphone design, construction and material**
- Miniaturization – in a small-size device the cooling is more challenging
- Increasing transistor number per processor
  - Although each transistor generates only a tiny bit of heat as it operates, many transistors operating at once make the computer chips get very hot
- High density of components – the heat generated by a smartphone is a sum of the heat from each heat-generating components
- Faulty thermal management design
- Low RAM - Small RAM memory size results in increased heat generation by the processor

**Operation mode**
- Running resource intensive application (games, streaming, videos, hot spot searching mode for WIFI connection…)
- Fast battery charging
- Too many task running - the applications running in background are a "hidden" source of smartphone heating

**Environment**
- Ambient temperature too hot
- Cell phone stored in inappropriate areas (pockets, bags, virtual reality google…)
- Deteriorated heat exchange with the environment due to smartphone cover

**Damage**
- Battery failure/damage
WHICH PACKAGES ARE USED IN SMARTPHONES?

• QFN (quad-flat no-leads)
  - Main applications are in automotive; very rare in mobile phones

• Fan-in approach (WLCSP–Wafer-Level Chip Scale Package)
  - Interconnects are within the die surface area
  - Used in mobile phones, RF devices, power devices
  - Limitation by the chip size

• FC-BGA
  - FC-CSP/FC-BGA are the most standard packages, used in almost all smartphones today.

• Fan-out approach
  - Interconnects not limited by the die size
  - Good thermal conductivity
  - Good electrical conductivity
  - More recent approach, therefore still higher cost compared to traditional packaging solutions
PoP packaging Technologies

The electrically conductive material (18 in the Shinko patent) can include a solid core formed from a metal like copper, which solid core can be coated with a solder.

The copper core solder ball seems to be dropped and refloowed before molding. The copper ball has a small shift during the reflow. The presence of the copper ball prevent a shrink of the solder ball during the reflow and also offers better electrical and heat conductivity.

FC-PoP is the conventional PoP packaging. Two actors uses this type of package: Huawei, Samsung. One of the two other actors (Qualcomm) uses different approach with Shinko’s MCeP who choose advanced substrate to support the AP.
In the cross-section, two main choices have been made by the End-Users OEM with the PoP. Apple and Qualcomm choose advanced packaging through TSMC and Shinko. Huawei and Samsung choose conventional packaging through Amkor and Samsung.

TSMC and Shinko managed to get thin packaging compared to traditional PoP.

In each PoP, the memory package has approximately the same thickness, even if one of them doesn’t use stack memory.

The high reliability of copper-based through molding via solution is obvious when we compared the cross section of the packages.

Depending on the packaging manufacturer, TMV could have some distortion form or unwanted connection.

Even if Samsung and Amkor use the same PoP technology, some differences can be seen. For Samsung, the via have a better definition than Amkor.

With 3 RDL layers, TSMC managed to avoid the use of top PCB with small L/S dimensions.
Application processor I/O count & Line/Space width

<table>
<thead>
<tr>
<th>Line/Space (µm/µm)</th>
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<td>2000</td>
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<td>1800</td>
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iPhone Physical Analysis
Samsung Physical Analysis
Huawei Physical Analysis
LG Physical Analysis
Xiaomi Physical Analysis
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About System Plus
PCB Design

The Printed Circuit Board (PCB) has large potential for smartphone thermal management improvement. In fact the PCB is in contact with the heat generating devices, but it has a large area to dissipate the heat.

There are different parameters to take in account in the analysis of the PCB design.
Heat Spreader

HEAT SPREADER are thin layer of material which are used to distribute heat across the telephone to prevent hotspot and provide lateral heat conduction.

They can be made of different materials:
- Aluminium
- Graphite
- Copper
- ......

And have different shapes:
- Foils
- Adhesive tapes
- Sheets
Apple utilizes a fabless production model. They rely on independent third-party suppliers to perform manufacturing and assembly.

**Apple Processor Supply Chain History**

**Die Manufacturing**
- Gate-last HKMG 20 nm
- 89 mm²

**Package Manufacturing**
- FC-PoP

**Die Technology & Area**
- Gate-last HKMG 20 nm
- 96 mm²

**Package Technology**
- FC-PoP

**Comparison Years:**
- 2014
- 2015
- 2016
- 2017

**Die Technology & Area:**
- Gate-last HKMG 20 nm
- 89 mm²

**Package Technology:**
- FC-PoP

**Package Manufacturing**
- SAMSUNG

**Die Technology & Area:**
- FinFET 14 nm
- 96 mm²

**Package Technology:**
- FC-PoP

**Package Manufacturing**
- SAMSUNG

**Die Technology & Area:**
- FinFET 16 nm
- 104.5 mm²

**Package Technology:**
- FC-PoP

**Package Manufacturing**
- SAMSUNG

**Die Technology & Area:**
- FinFET 16 nm
- 125 mm²

**Package Technology:**
- inFO-PoP

**Package Manufacturing**
- SAMSUNG

**Die Technology & Area:**
- FinFET 10 nm
- 87.7 mm²

**Package Technology:**
- inFO-PoP

**Package Manufacturing**
- SAMSUNG
Apple iPhone 6s Plus Teardown

Telephone surface: 12,323 mm²

Apple iPhone 6s Plus Front View

Apple iPhone 6s Plus SideView
Apple iPhone 6s Plus Heating zones

- Li-ion Polymer Battery (3.80V, 10.45Wh, 2750mAh)

The rear case supports the battery and it is in direct contact with it and the PCB board.
Apple iPhone 6s Plus Processor Board

Main Board (Top Side)

- PCB area: $1,848\text{mm}^2$

Main Board (Rear Side)
PCB iPhone 6s Plus

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A9 Package Cross-Section
Apple iPhone 7 Plus Opening
Apple iPhone 7 Plus Teardown

The Microprocessor and the baseband processor shield is cover by a thin film of copper. This thin film is in contact with the metal frame on the back of the display.
Apple iPhone 7 Plus Teardown

The thermal heat transfer seems to be from the baseband processor to the display, where it can radiate out to the side. Since the microprocessor uses TSMC’s inFO technology it requires less thermal management.

- The A10 application processor is under the SDRAM chip in PoP mode (Package on Package).

The Microprocessor and the baseband processor is covered by a thermal grease, two EMI shields and a thin film of copper. This thin film is in contact to the metal frame on the back of the display.
PCB cross section
A10 Package Cross-Section
A10 Package Cross-Section
A10 Package Cross-Section
Apple iPhone X Teardown
Apple iPhone X Heating zones
Apple iPhone X Processor Board
Samsung utilizes a fully integrated IDM model. They perform design, manufacturing, assembly and wafer testing.
Samsung Galaxy S7 Teardown EMI (US version)
Exynos 8 Package Cross-Section
Exynos 8 Package Cross-Section
Samsung Galaxy S8 Teardown

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Heat Pipes
Heat Pipes
Huawei utilizes a fabless production model. They rely on independent third-party suppliers to perform manufacturing and assembly.
Huawei P9 Opening

- Rear Camera Module
- Front Camera Module
- Li-ion Polymer Battery (3.8V, 11.46Wh, 3000mAh)
- Back case
Huawei P9 Processor Board

Main Board (Front Side)

Main Board (Top Side)
Kirin 955 Package View & Dimensions

- Package: xxxx ball PoP BGA
- Dimensions: xxx x xxxxxxx mm
- Pin Pitch: xxx mm
LG utilizes a fabless production model. They rely on independent third-party suppliers to perform manufacturing and assembly.
LG G6 Opening

- Front Camera Module
- Li-ion Polymer Battery (3.82V, xxxWh, 3000mAh)
- Rear Camera Module
- Back cover
Related Reports

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Packaging
- Advanced RF SiPs for Cell Phones: Reverse Costing Overview
- 2016 Comparison of Application Processor Packaging

MARKET AND TECHNOLOGY REPORTS - YOLE DÉVELOPPEMENT

Batteries / Energy Management
- Market Opportunities for Thermal Management Components in Smartphones
Business Models Fields of Expertise

- Custom Analyses
  (>130 analyses per year)

- Reports
  (>40 reports per year)

- Costing Tools

- Trainings

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IBAN: FR76 3005 6009 5509 5500 0323 439

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MAIL: SYSTEM PLUS CONSULTING
21 rue La Noué Bras de Fer
44200 Nantes – France

Contact:

EMAIL: sales@systemplus.fr
TEL: +33 2 40 18 09 16

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A complete range of services and costing tools to provide in-depth production cost studies and to estimate the objective selling price of a product is available.

Our services:

TECHNOLOGY ANALYSIS - COSTING SERVICES - COSTING TOOLS - TRAININGS

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The delivery schedule on the purchase order is given for information only and cannot be strictly guaranteed. Consequently any reasonable delay in the delivery of services will not allow the buyer to claim for damages or to cancel the order.

7. ENTRUSTED GOODS SHIPMENT
The transport costs and risks are fully born by the Buyer. Should the customer wish to ensure the goods against lost or damage on the base of their real value, he must imperatively point it out to System Plus Consulting when the shipment takes place. Without any specific requirement, insurance terms for the return of goods will be the carrier current ones (reimbursement based on good weight instead of the real value).

8. FORCE MAJEURE
System Plus Consulting responsibility will not be involved in non execution or late delivery of one of its duties described in the current terms and conditions if these are the result of a force majeure case. Therefore, the force majeure includes all external event unpredictable and irresistible as defined by the article 1148 of the French Code Civil?

9. CONFIDENTIALITY
As a rule, all information handed by customers to system Plus Consulting are considered as strictly confidential. A non-disclosure agreement can be signed on demand.

10. RESPONSABILITY LIMITATION
The Buyer is responsible for the use and interpretations he makes of the reports delivered by System Plus Consulting. Consequently, System Plus Consulting responsibility can in no case be called into question for any direct or indirect damage, financial or otherwise, that may result from the use of the results of our analysis or results obtained using one of our costing tools.

11. APPLICABLE LAW
Any dispute that may arise about the interpretation or execution of the current terms and conditions shall be resolved applying the French law.
It the dispute cannot be settled out-of-court, the competent Court will be the Tribunal de Commerce de Nantes.