Apple A11 Application Processor

Second generation of TSMC’s inFO packaging

PACKAGING report by Stéphane ELISABETH

February 2018 – version 1
Table of Contents

Overview / Introduction  4
  o Executive Summary
  o Reverse Costing Methodology

Company Profile  8
  o Apple
  o Apple APE Portfolio
  o Fan-Out Packaging
  o TSMC inFO Technology
  o Apple iPhone 8 & X Teardown
  o Fan-Out Market

Physical Analysis  22
  o Summary of the Physical Analysis  23
  o Packaging  25
    ✓ Package Views, Marking & Dimensions
    ✓ Package X-Ray
    ✓ Package RDL Deprocessing
    ✓ Package Memory: X-Ray view & Opening
    ✓ Package Opening
    ✓ Board Cross-Section: Via Frame, PCB, Dimensions
    ✓ Package Cross-Section: TiV, Adhesive, RDLs
    ✓ Package Process
    ✓ Summary of Physical Data
  o Land-Side Capacitor  65
    ✓ Die Views & Dimensions
    ✓ Die Deprocessing & Delayering
    ✓ Die Process
    ✓ Die Cross-Section
    ✓ Die Process Characteristics

  o Application Processor  87
    ✓ Die Views, Marking & Dimensions
    ✓ Die Cross-Section
    ✓ Die Process Characteristics

Physical Comparison  94
  o Apple’s APE Series: A9, A10, A11
  o APE’s PoP Technology: Standard PoP, MCeP, inFO

Manufacturing Process  98
  o APE Die Front-End Process & Fabrication Unit
  o Deep Trench Capacitor Die Front-End Process Flow
    & Fabrication Unit
  o inFO Packaging Process Flow & Fabrication unit

Cost Analysis  117
  o Summary of the cost analysis  118
  o Yields Explanation & Hypotheses  119
  o APE die  122
    ✓ Wafer & Die Front-End Cost
    ✓ Preparation Wafer Cost
  o LSC die  126
    ✓ Wafer & Die Front-End Cost
    ✓ Frond-End cost per Process Steps
  o inFO Packaging
    ✓ inFO Wafer Cost
    ✓ inFO Front-End Cost per Process Steps
    ✓ Component Cost

Company services  136
Executive Summary

• This full reverse costing study has been conducted to provide insight on technology data, manufacturing cost and selling price of the Apple A11.

• Comparing the Apple iPhone X and the Apple iPhone 8, the two flagship has different way to integrate the main board. On the iPhone X, the main board is using special PCB technology from AT&S to reduce about 53% of the main board footprint. AT&S has managed to use two side mounted PCB and a via frame to compact the main board. The APE is located inside the structure under the DRAM package using PoP technology. This new version comes along with a new land-side decoupling capacitors (LSC) technology.

• The Apple A11 is a wafer-level package using new generation of TSMC’s packaging technology with copper pillar as Through inFO Via (TiV) to replace the well-known Through Molded Via (TMV) technology. Compared to standard PoP technology, Apple still have a head start with the inFO packaging and its innovations: Copper Pillars, Redistribution layer, silicon high density capacitor integration, ...

• In this report, the complete packaging is analyzed from the DRAM memory to the LSC developed by TSMC. The report includes a complete cost analysis and price estimation of the device based on a detailed description of the packaging. It also features a complete technology comparison with standard PoP and Shinko’s MCEP PoP packaging used in the market.
Apple iPhone 8 & X Teardown

Physical Analysis
Physical Comparison
Manufacturing Process Flow
Cost Analysis
Feedbacks
About System Plus

Apple iPhone 8 & X Teardown
Summary of the Physical Analysis

infO Assembly:

- Packaging
- Board Cross-Section
- Package Cross-Section
- Land-side Capacitor
- Application Processor

APE Die:

- Process: 
- Placement:

Copper Pillar

Apple A11 Assembly
©2017 by System Plus Consulting
Package Views & Dimensions

- Package:
- Dimensions:
- Pin Pitch:

Package Top View – Optical View
©2018 by System Plus Consulting

Package Bottom View – Optical View
©2018 by System Plus Consulting

Package Side View – Optical View
©2018 by System Plus Consulting
The X-Ray view reveals the passives/chips disposition under the package.
Package Overview – RDL #3

- Measured Line/Space Width in Bottom view:
  - RDL #3:

Package Opening View – Optical View

Package Opening View – Bottom View – L/S Measurement

Package Overview – Bottom View – Third RDL
A11 & Samsung – Package X-Ray

The X-Ray view reveals the DRAM chips disposition.
Board Cross-Section – Via Frame

Package Cross-Section
©2018 by System Plus Consulting

Board Cross-Section – Optical View
©2018 by System Plus Consulting

©2017 by System Plus Consulting | Apple A11 with TSMC inFO Packaging
Package Cross-Section

- Total thickness (without balls):
  - Memory package thickness: [value]
  - Memory dies thickness: [value]
  - PCB thickness: [value]
  - Processor package thickness (with adhesive):
    - Die thickness: [value]
    - RDL thickness: [value]

Cross-Section Plan
©2018 by System Plus Consulting

Package Cross-Section – SEM View
©2018 by System Plus Consulting
Package Cross-Section – RDLs

- Packaging
- Board Cross-Section
- Package Cross-Section
- Land-side Capacitor
- Application Processor

Physical Comparison

Manufacturing Process Flow

Cost Analysis

Feedbacks

About System Plus
Land-Side Decoupling Capacitor – Die View & Dimensions

Package:
Dimensions:
Pitch:
Pad number:
Nb of PGDW per 8-inch wafer:
Land-Side Decoupling Capacitor – Die Process
Land-Side Decoupling Capacitor – Die Cross-Section
APE Die Dimensions

- Die Area:

- Nb of PGDW per 12-inch wafer:

- Pad number:
Package Comparison – Apple’s APE

Overview / Introduction
Company Profile & Supply Chain
Physical Analysis
Physical Comparison
- Apple APE’s Series
  - APE’s PoP Technology
Manufacturing Process Flow
Cost Analysis
Feedbacks
About System Plus

Board Cross-Section – Optical View
©2018 by System Plus Consulting
Deep Trench Capacitor Front-End Process

- **IPD Front-End Process:**
  - Substrate:
  - Process type:
  - Metal layers:
  - Polysilicon layers:
  - Lithography steps:
Packaging Process

The package is manufactured and assembled by TSMC in Taiwan.

- inFO Process:
  - Package Type:
  - Carrier:
  - Process type:

- Test:
  - Test type:

Drawing not at scale
## inFO Packaging Cost

<table>
<thead>
<tr>
<th>Package Manufacturing Cost</th>
<th>Low Yield Cost</th>
<th>Low Yield Breakdown</th>
<th>Medium Yield Cost</th>
<th>Medium Yield Breakdown</th>
<th>High Yield Cost</th>
<th>High Yield Breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass Carrier Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clean Room Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumable Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield losses Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Package Manufacturing Cost Breakdown (Medium Yield)

- **Cost Breakdown**
- **Gross margin**
- **Package Manufacturing Price**
Related Reports

REVERSE COSTING ANALYSES - SYSTEM PLUS CONSULTING

PACKAGING
- NXP SCM-i.MX6 Quad High Density Fan-Out Wafer-Level System-in-Package
- Qualcomm VIVE® QCA9500 High Density WiGig/WiFi 802.11ad Chipset for the 60 GHz Band
- TSMC Integrated Fan-Out Package

MARKET AND TECHNOLOGY REPORTS - YOLE DÉVELOPPEMENT

ADVANCED PACKAGING
- Fan-Out: Technologies and Market trends 2017
- Equipment and Materials for Fan-Out Packaging 2017

PATENT ANALYSIS - KNOWMADE

ADVANCED PACKAGING
- Fan-Out Wafer Level Packaging Patent Landscape
Until 2015, Apple used to integrate its application processor engine (APE) in standard Package-on-Package (PoP) packaging. Starting in 2016, with the Apple A10 APE in the Apple iPhone 7, TSMC has brought a breakthrough fan-out technology called integrated Fan-Out (inFO) packaging to the market. This is still the most innovative, powerful and cost-effective fan-out packaging technology for the APE. For its latest flagships, the Apple iPhone 8 and tenth’s anniversary iPhone X, Apple has renewed its collaboration with TSMC by using the new generation of inFO packaging for the Apple A11 APE.

Comparing the iPhone X and the iPhone 8, Apple and its partners have integrated the two flagships’ main boards differently. In the iPhone X, the main board uses special printed circuit board (PCB) technology from AT&S to reduce its PCB footprint by about 15%. To do this, AT&S uses two stacked PCBs with components mounted on both sides and a via frame. The APE is located inside the structure, under the DRAM package, using PoP technology. This new version also features new land-side decoupling capacitor (LSC) technology.

The Apple A11 is a wafer-level package using the new generation of TSMC’s packaging technology. It uses copper pillars, called Through inFO Vias (TiVs), to replace the well-known Through Molded Via (TMV) technology. Apple still outperforms standard PoP technology thanks to the inFO packaging and its innovations, which include copper pillars, redistribution layers and silicon high density capacitor integration.

This report analyzes the complete package, from the DRAM memory to the LSC developed by TSMC. The report includes a comprehensive cost analysis and price estimation of the device based on detailed description of the packaging. It also features a detailed technology comparison with standard PoP and Shinko’s MCeP PoP packaging.
**TABLE OF CONTENTS**

Overview/Introduction

Apple Company Profile and inFO Technology

Apple iPhone 8 and iPhone X Teardown

Physical Analysis
- Physical Analysis Methodology
- A11 Packaging Analysis
  - Package view and dimensions: X-ray, RDL deprocessing, RDL line/space width
  - Package opening: DRAM memories, APE die
  - Board and package cross-section: via frame, main board PCB, TiV, adhesives, RDLs
- Land-Side Decoupling Capacitor
  - Die view and dimensions
  - Die overview and delayering
  - Die cross-section
  - Die process

Manufacturing Process Flow
- Packaging Fabrication Unit
- inFO Package Process Flow
- Deep Trench Capacitor (DTC) Chip Fabrication Unit
- DTC Process Flow

Cost Analysis
- Summary of the Cost Analysis
- Supply Chain Description
- Yield Hypotheses
- A11 Die Cost Analysis
  - Wafer cost
  - Die cost
- DTC Die Cost Analysis
  - Wafer cost
  - Die cost
- inFO Package Cost Analysis
  - inFO wafer front-end cost
  - inFO cost per process step
- Final Test Cost
- Component Cost

Estimated Price Analysis

Technology comparison with Samsung’s PoP, Shinko’s MCeP and the previous inFO generation from the Apple A10

**AUTHORS:**

Dr. Stéphane Elizabeth

Stéphane has a deep knowledge of materials characterizations and electronics systems. He holds an Engineering Degree in Electronics and Numerical Technology, and a PhD in Materials for Microelectronics.

Nicolas Radufe (Lab)

Nicolas is in charge of physical analysis. He has a deep knowledge in chemical and physical analyses. He previously worked in microelectronics R&D for CEA/LETI in Grenoble and for STMicroelectronics in Crolles.

**ANALYSIS PERFORMED WITH OUR COSTING TOOL 3D PACKAGE COSIM+**

System Plus Consulting offers powerful costing tools to evaluate the production cost and selling price from single chip to complex structures.

3D Package Cosim+

Cost simulation tool to evaluate the cost of any Packaging process: Wafer-level packaging, TSV, 3D integration...
### RELATED REPORTS

<table>
<thead>
<tr>
<th>Report Description</th>
<th>Date</th>
<th>Pages</th>
<th>Full report: EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>NXP SCM-i.MX6 Quad High Density Fan-Out Wafer-Level System-in-Package</td>
<td>June 2017</td>
<td>132</td>
<td>3,490*</td>
</tr>
<tr>
<td>Qualcomm VIVE® QCA9500 High Density WiGig/WiFi 802.11ad Chipset for the 60 GHz Band</td>
<td>January 2018</td>
<td>145</td>
<td>3,990*</td>
</tr>
<tr>
<td>TSMC Integrated Fan-Out (inFO) Package in Apple’s A10 Application Processor</td>
<td>October 2016</td>
<td>100</td>
<td>3,490*</td>
</tr>
</tbody>
</table>

The first ultra-small multi-die low power module with boot memory and power management integrated in a package-on-package compatible device for the Internet of Things.

Disruptive double side molded system-in-package-based chipset for millimeter-wave applications targeting consumer devices, including integrated antennae.

Reverse engineering and costing of the new inFO packaging technology from TSMC used for Apple’s latest A10 application processor, found in the iPhone 7 and 7 Plus.

### ANNUAL SUBSCRIPTION OFFER

Each year System Plus Consulting releases a comprehensive collection of new reverse engineering & costing analyses in various domains.

You can choose to buy over 12 months a set of 3, 4, 5, 7, 10 or 15 Reverse Costing® reports.

**Up to 47% discount!**

More than 60 reports released each year on the following topics (considered for 2018):

- **MEMS & Sensors:**
  - Accelerometer - Environment - Fingerprint - Gas - Gyroscope - IMU/Combo - Microphone - Optics - Oscillator - Pressure
- **Power:**
  - GaN - IGBT - MOSFET - Si Diode - SiC
- **Imaging:** Camera - Spectrometer
- **LED & Laser:** UV LED - VCSEL - White/blue LED
- **Packaging:**
  - 3D Packaging - Embedded - SIP - WLP
- **Integrated Circuits:**
  - IPD - Memories - PMIC - SoC
- **RF:**
  - FEM - Duplexer
- **Systems:**
  - Automotive - Consumer - Energy - Telecom
ORDER FORM

Please process my order for “Apple A11 inFO-PoP” Report

☐ Apple A11 inFO-PoP: EUR 3,490*

*For price in dollars please use the day’s exchange rate. All reports are delivered electronically in pdf format. For French customer, add 20 % for VAT.

SHIP TO
Name (Mr/Ms/Dr/Pr):
Job Title:
Company:
Address:
City: State:
Postcode/Zip:
Country:
VAT ID Number for EU members:
Tel:
Email:
Date:
Signature:

PAYMENT
DELIVERY on receipt of payment:

By credit card:
Number: _____________________________
Expiration date: __/__/____
Card Verification Value: __________

By bank transfer:
BANK INFO: HSBC, 1 place de la Bourse, F-69002 Lyon, France,
Bank code: 30056, Branch code: 00170
Account No: 0170 200 156 587
SWIFT or BIC code: CCFRFRPP
IBAN: FR76 3005 6001 7010 7020 0156 587

Return order by:
• FAX: +33 (0)472 83 01 83
• MAIL: YOLE DEVELOPPEMENT,
  75 Cours Emile Zola, F - 69100 Lyon - Villeurbanne

Contact:
• Japan: Miho - Ohtake@yole.fr
• Greater China: Mavis - Wang@yole.fr
• Asia: Takashi - Onozawa@yole.fr
• EMEA: Lizzie - Levenez@yole.fr
• North America: Steve – laferriere@yole.fr
• General: info@yole.fr

BILLING CONTACT
The present document is valid till April 15, 2018

First Name: _____________________________ Last Name: _____________________________
Email: _____________________________ Phone: _____________________________

ABOUT YOLE DEVELOPPEMENT
Founded in 1998, Yole Développement has grown to become a group of companies providing marketing, technology and strategy consulting, media and corporate finance services. With a strong focus on emerging applications using silicon and/or micro manufacturing, the Yole Développement group has expanded to include more than 50 collaborators worldwide covering MEMS, Compound Semiconductors, LED, Image Sensors, Optoelectronics, Microfluidics & Medical, Advanced Packaging, Manufacturing, Nanomaterials, Power Electronics and Batteries & Energy Management.
The “More than Moore” company Yole, along with its partners System Plus Consulting, Blumorpho and KnowMade, support industrial companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to grow their business.

CUSTOM STUDIES
• Market data & research, marketing analysis
• Technology analysis
• Reverse engineering & costing services
• Strategy consulting
• Patent analysis
More information on www.yole.fr

TECHNOLOGY & MARKET REPORTS
• Collection of technology & market reports
• Manufacturing cost simulation tools
• Component reverse engineering & costing analysis
• Patent investigation
More information on http://www.i-micronews.com/reports.html

MEDIA
• i-Micronews.com, online disruptive technologies website and its weekly e-newsletter, @Micronews
• Communication & webcasts services
• Events: Yole Seminars, Market Briefings
More information on http://www.i-micronews.com/media-kit.html

Distributed by

Performed by
**TERMS AND CONDITIONS OF SALES**

**1. Scope and Definitions**

- **Definitions**: “Acceptances”. Action by which the buyer accepts the terms and conditions of sale in their entirety. It is done by signing the purchase order which mentions “I hereby accept Yole’s Terms and Conditions of Sale”.

- **Buyer**: Any business user (i.e. any person acting in the course of its business activities, for its business needs) entering into the following general conditions to the exclusion of consumers acting in their personal interest.

- **Contracting Parties** or “Parties”: The Seller on the one hand and the Buyer on the other hand.

- **manufacturer’s rights**: any rights held by the Seller in its Products, including any patents, trademarks, registered models, designs, copyrights, inventions, commercial secrets and know-how, technical information, company or trading names and any other intellectual property rights or similar in any part of the world, notwithstanding the fact that they have been registered or not and including any pending registration of one of the above mentioned rights.

- **License**: For the reports and databases, 3 different licenses are proposed. The buyer has to choose one license:

  - **Corporate license**: one person at the company can use the report, or
  - **Corporate license**: the company can use the report without any limitation, or
  - **Corporate license**: the company can use the report for a particular purpose, with respect to the Products. Although the Seller shall take reasonable care to ensure that the Products do not contain any viruses, worms, Trojan horses or other codes containing destructive or prearranged programs before making the Products available, the Seller cannot guarantee that any Product will be free from infection.

- **Price**: The Seller shall not be liable for any delay in performance directly or indirectly caused by or resulting from acts of nature, fire, flood, accident, riot, war, government intervention, embargoes, strikes, labor difficulties, equipment failure, late deliveries by suppliers or other difficulties which are beyond the control, and not the fault of the Seller.

- **Product(s)**: All the provisions of these Terms and Conditions are for the benefit of the Seller itself, but also for its licensors, employees and agents. Each of them is entitled to assert and enforce those provisions against the Buyer.

**2. Place and Language**

- **Language**: All notices under these Terms and Conditions shall be given in writing. They shall be effective upon receipt by the other Party. The Seller may, from time to time, update these Terms and Conditions and the Buyer, is deemed to have accepted the latest version of these terms and conditions, provided they have been communicated to him in due time.

- **Governing law and jurisdiction**: The Seller shall have exclusive jurisdiction upon such issues.

- **Termination**: If the Buyer cancels the order in whole or in part or postpones the date of taking delivery, the Seller shall indemnify the Buyer for the entire costs that have been incurred as at the date of notification by the Buyer of such delay or cancellation. This may also apply for any other direct or indirect consequential loss that may be borne by the Seller, following this decision. This decision 2.7 that the Buyer has on non-breaching Party under this paragraph 2.6, the non-breaching Party shall send a notification to the other Party of the recorded delivery letter upon which, after a period of thirty (30) days without solving the problem, the non-breaching Party shall be entitled to terminate all the pending orders, without being liable for any compensation.

- **Drafts**: All the provisions of this paragraph 2.8, the Seller shall have exclusive jurisdiction upon such issues.

**3. Price, invoicing and payment**

- **Price**: The Seller agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party. The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party. The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party.

- **Invoicing**: The Products sold shall be sold to the Buyer - within [1] month from the order for Products already released; or

- **Payment**: All the information contained in the Products has been obtained from sources believed to be reliable. The Seller does not warrant the accuracy, completeness adequacy or reliability of such information, which cannot be guaranteed to be free from errors.

- **Price**: The Seller agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party. The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party.

- **Payment**: All the information contained in the Products has been obtained from sources believed to be reliable. The Seller does not warrant the accuracy, completeness adequacy or reliability of such information, which cannot be guaranteed to be free from errors.

- **Price**: The Seller agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party. The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party.

**4. General terms and conditions**

- **Terms and Conditions of Sale**: The Seller agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party. The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party.

- **Breach of Conditions and Cancellation**: In the event of breach by one Party under these conditions or the order, the non-breaching Party may send a notification to the other Party of the recorded delivery letter upon which, after a period of thirty (30) days without solving the problem, the non-breaching Party shall be entitled to terminate all the pending orders, without being liable for any compensation.

**5. Intellectual Property**

- **Copyright**: The information contained in the Products is protected by various international treaties and national laws governing intellectual property. The Seller grants the Buyer a non-exclusive, non-transferable and non-sublicensable right to use the information contained in the Products for the duration of the license or contract under which the information is acquired, and shall have the right to use the information in accordance with these terms and conditions, provided they have been communicated to him in due time.

**6. Contracts and sales**

- **Contracts and sales**: The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party. The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party.

**7. Miscellaneous**

- **Miscellaneous**: The Seller agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party. The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party.

- **Miscellaneous**: The Seller agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party. The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party.

- **Miscellaneous**: The Seller agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party. The Buyer agrees not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to an unauthorized third party.
Business Models Fields of Expertise

- Custom Analyses
  (>130 analyses per year)
- Reports
  (>40 reports per year)
- Costing Tools
- Trainings

Company Profile & Supply Chain
Physical Analysis
Physical Comparison
Manufacturing Process Flow
Cost Analysis
Feedbacks
About System Plus
  - Company services
  - Related reports
  - Contact
  - Legal

©2017 by System Plus Consulting | Apple A11 with TSMC inFO Packaging