Camera Module Comparison 2021 Vol. 2 – Apple iPhone Evolution

Apple's camera design choices from the iPhone 6S Plus to the 12 Pro Max.

SPR21553 - Imaging report by Peter BONANNO
Physical analysis by Véronique LE TROADEC & Guillaume CHEVALIER

June 2021 – Sample
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Executive Summary

Over 1.3B smartphones shipped in 2020, and 15% of those were iPhones. Apple is widely considered an innovation leader, and iPhone cameras are consistently ranked among the best in the industry. Continuing our series of camera module comparison reports, we summarize the results of detailed physical analyses and costing studies to compare the cameras of the iPhone 6S Plus, 7 Plus, 8 Plus, X, XS Max, 11 Pro Max, and 12 Pro Max. This report aims to offer insight into the physical and cost evolution of the camera modules and CMOS image sensors in the last six years of Apple flagship smartphones.

The analysis covers the rear and front-facing RGB camera modules as well as the front-facing Near Infrared (NIR) module. This includes the complete structure, design, and all components of the camera modules. It covers the dimensions, technology nodes and stacking technology in the CMOS image sensors. The rear-facing LiDAR camera in the 12 Pro Max is not covered, but the reader is encouraged to discover the essentially identical LiDAR module in the related report SP20557 - Apple iPad Pro LiDAR Module.

Over the years, the rear camera has evolved with the market trend from a single to dual and finally a triple camera system. The front camera has also evolved from a single camera to the dual-camera TrueDepth system. The overall design of the AutoFocus/Optical Image Stabilisation (AF/OIS) system has remained very consistent until the introduction of Sensor-shift OIS in the iPhone 12 Pro Max. See our dedicated report SPR21611 - Apple iPhone 12 Pro Max Rear Camera for a deep dive into this technology.

All rear sensors have 12 megapixels (Mp) despite the trend among other leading OEMs to go as high as 108 Mp. This has allowed Apple to sometimes retain image sensors between iPhone generations while improving camera performance from module upgrades and algorithm tweaks.
Executive Summary

The reverse costing analysis is conducted in 3 phases:

Teardown analysis
- Package is analyzed and measured
- The dies are extracted in order to get overall data: dimensions, main blocks, pad number and pin out, die marking
- Setup of the manufacturing process.

Costing analysis
- Setup of the manufacturing environment
- Cost simulation of the process steps

Selling price analysis
- Supply chain analysis
- Analysis of the selling price
## Camera Overviews

### Smartphone Specifications

<table>
<thead>
<tr>
<th>Smartphone</th>
<th>Launch</th>
<th>N° of Modules</th>
<th>Camera position</th>
<th>Module Name</th>
<th>Camera Module Specification</th>
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<tbody>
<tr>
<td>iPhone 6S Plus</td>
<td>Sep 2015</td>
<td>2</td>
<td>Front</td>
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<td>5 MP, f/2.2, 31 mm, 1.12 μm</td>
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<td>IR/depth</td>
<td>1.4 Mp, f/2.0, 2.8 μm infrared</td>
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<td>12 MP, f/1.8, 28 mm (wide), 1/3&quot;, 1.22 μm, dual pixel PDAF, OIS</td>
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<td>Telephoto</td>
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<td>1.4 Mp, f/2.0, 2.8 μm infrared</td>
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<td>12 MP, f/1.8, 26 mm (wide), 1/2.55&quot;, 1.4 μm, dual pixel PDAF, OIS</td>
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<td>IR/depth</td>
<td>1.4 Mp, f/2.0, 2.8 μm infrared</td>
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<td>LiDAR*</td>
<td>0.03 MP (not covered in this report*)</td>
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*We have performed a full analysis of the essentially identical LiDAR in the iPad Pro (SP20557)
Camera and Camera Module Overview

Front Single Cameras:

Front Modules:

TrueDepth Front Camera:

Manufacturing Process Flow
Cost Analysis
Cost Comparison
Selling Price Analysis
Related Analyses
About System Plus

Cameras and camera modules are to scale for comparison.

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CMOS Image Sensor Overview

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   Camera Overviews
      Physical Comparison
         Front Cameras
         Dual Cameras
         Triple Cameras
      Overview of Physical Analysis
         iPhone 12 Pro Max
         iPhone 11 Pro Max
         iPhone XS Max
         iPhone X
         iPhone 8 Plus
         iPhone 7 Plus
         iPhone 6S Plus

Manufacturing Process Flow
Cost Analysis
Cost Comparison
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Front:

Front IR: CIS retained

Main/
Wide:

Telephoto:

CIS are to scale for comparison.

CIS retained

Ultra Wide:

CIS retained

SAMPLE
Camera Module Physical Comparison

## Front-Facing Camera

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<thead>
<tr>
<th>Smartphone</th>
<th>Year of launch</th>
<th>Type of Camera</th>
<th>CM/AF</th>
<th>OIS</th>
<th>AF</th>
<th>TTL (mm)</th>
<th>Lens Number</th>
<th>Lens Average diameter</th>
<th>Filter Material</th>
<th>PCB substrate</th>
<th>Conn Type</th>
<th>Module Packing Length (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
<th>Mod Vol (mm³)</th>
<th>Low Volume per Side (mm³)</th>
<th>CM Cost</th>
<th>CM Price</th>
<th>CM Price per side</th>
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## Rear-Facing Camera

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<th>Type of Rear Camera</th>
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<th>AF</th>
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<th>Height (mm)</th>
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</table>

CM: Camera Module  
OIS: Optical Image Stabilization  
AF: Autofocus  
TTL: Through-The-Lens  
CM Cost: Cost to manufacture the camera module  
CM Price: Cost plus manufacturer’s gross margin  
CM price per side: total price of all camera modules on the front or back side of the phone
# CMOS Image Sensor Physical Comparison

## Front-Facing Camera

<table>
<thead>
<tr>
<th>Smartphone</th>
<th>Year of launch</th>
<th>Type of Camera</th>
<th>Sensor MF</th>
<th>Sensor die Area (mm²)</th>
<th>Total Sensor die Area</th>
<th>Res. (Mpx)</th>
<th>Pixel Size (µm)</th>
<th>Pixel array Length (mm)</th>
<th>Width (mm)</th>
<th>Diag. (mm)</th>
<th>CIS Cost</th>
<th>CIS Price</th>
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## Rear-Facing Camera

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<th>Pixel Size (µm)</th>
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Res.: Resolution (number of pixels)
Ffactor: Pixel array form factor (Width / Length)
Diag.: Length of diagonal of pixel array

CIS: CMOS Image Sensor
CIS Cost: Cost to manufacture the CIS
CIS Price: Cost plus manufacturer’s gross margin
Front Camera CIS Physical Comparison

Front:

Front IR:

CIS are to scale for comparison.

<table>
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<tr>
<th>Smartphone</th>
<th>iPhone 6S Plus</th>
<th>iPhone 7 Plus</th>
<th>iPhone 8 Plus</th>
<th>iPhone X</th>
<th>iPhone XS Max</th>
<th>iPhone 11 Pro Max</th>
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</table>

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iPhone 12 Pro Max – Camera Modules Physical Analysis Overview

Total Camera Volume:

Total CM Cost:

Total CM Price:

Release date: November 2020

Manufacturing Process Flow

Cost Analysis

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Selling Price Analysis

Related Analyses

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  - Front Cameras
  - Dual Cameras
  - Triple Cameras
- Overview of Physical Analysis
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  - iPhone 11 Pro Max
  - iPhone XS Max
  - iPhone X
  - iPhone 8 Plus
  - iPhone 7 Plus
  - iPhone 6S Plus

Manufacturing Process Flow
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iPhone 12 Pro Max – CMOS Image Sensors Physical Analysis Overview

Release date: November 2020

Total CIS Die Area:
Total CIS Die Cost:
Total CIS Die Price:

Front CIS Die Overview (taken from iPhone 11 Pro Max) ©2021 by System Plus Consulting

Front Infrared CIS Die (taken from iPhone X) Overview ©2021 by System Plus Consulting

Rear Main CIS Overview ©2021 by System Plus Consulting

Rear Ultra-Wide CIS Overview ©2021 by System Plus Consulting

Rear Telephoto CIS Overview (reconstruction super-imposed on PCB) ©2021 by System Plus Consulting

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Camera Module Structure

Manufacturing Processes
- Camera Module Structure
  - Conventional
  - Sensorshift OIS
- Sensor Manuf. Processes
  - with TSV stacking
  - with Hybrid stacking
  - Infrared
Camera Module Structure – Sensor-shift OIS

Apple has achieved an OIS system in which the sensor moves while the lens barrel remains immobile. It accomplishes this by using a flexible printed circuit that allows the sensor to move while maintaining connection with the motherboard.

Check out our teardown note for an animated demonstration of the motion:

For a deep dive into the Sensor-shift system, check out our dedicated report SPR21611 – Apple iPhone 12 Pro Max Rear Camera
Sony’s CMOS Image Sensor Cu-Cu Hybrid Bonding Process

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  - Infrared

Cost Comparison
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# CMOS Image Sensor – Front-End Cost Comparison

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<thead>
<tr>
<th>Logic Circuit</th>
<th>Front w/TSV</th>
<th>Front w/Hybrid</th>
<th>Rear w/TSV</th>
<th>Rear w/Hybrid</th>
<th>Front Infrared</th>
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<tbody>
<tr>
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<td>Raw wafer Cost (Si)</td>
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</table>
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  - Rear Camera Die Cost
- Module Cost Comparison
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- Camera Price Comparison

Detailed Physical Analysis
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Rear Image Sensor – Die Cost Comparison
## Rear Single and Dual Camera Modules – Cost of Components & Assembly

<table>
<thead>
<tr>
<th>Lens Module Rear Camera Cost</th>
<th>Camera Module Breakdown</th>
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<th>Rear Telephoto</th>
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### iPhone 12 Pro Max – Rear Main CM – Dimensions & Teardown

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  - iPhone XS Max
  - iPhone X
  - iPhone 8 Plus
  - iPhone 7 Plus
  - iPhone 6 Plus

#### Related Analyses

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**Pixel Array**

- *RGBG Bayer color filter array*
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**Die Area**

- *Pixel Array*
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**Pad Number**

- *Pixel Array*
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**CIS resolution**

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**Pixel Size**

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**Techno node**

- *Pixel Array*
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**Wafer Bonding**

- *Pixel Array*
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**CIS Die Overview**

- *Microlenses (1.7µm) – SEM View*
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**RGBG Bayer color filter array**

- *Camera Module with flex – Top, Back & Side View*
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---

**Mobile PCB Platform – view from top**

- *Camera Module Comparison 2021 Vol. 2 – Apple iPhone Evolution*
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iPhone 12 Pro Max – Rear Main CM – CIS Delaying & Cross-Section

- Front Cameras
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Rear Main Camera Module – various views
showing the position of the cross-sectional plane
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Cross-Section showing optical dimensions
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- Camera Modules Comparison 2021 – Vol. 1
- Smartphone Camera Module Comparison 2020 Vol. 2: Focus on Samsung
- Apple iPhone 12 Pro Max Rear Camera

By Yole Développement:
- CMOS Camera Module Industry for Consumer & Automotive 2020
- Status of the CMOS Image Sensor Industry 2020

RELATED TEARDOWN TRACKS

By System Plus Consulting:
- APPLE iPhone 6 plus 128GB
- APPLE iPhone X
- APPLE iPhone 12 Pro Max 5G

RELATED MONITORS

By Yole Développement:
- CMOS Image Sensor Quarterly Monitor – Q4 2020

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Our Core Activity: Reverse Costing®

A Structure, Process and Cost Analysis

Reverse Costing® consists of disassembling a device or a system in order to identify its technology and discern its manufacturing processes and then using in-house models and tools to determine its cost.
Fields Of Expertise

Electronic System

- Automotive
  - ADAS
  - Infotainment
  - Telematics
  - Electrification
  - Safety
- Consumer
  - Smartphone
  - Smart Home
  - Wearable
- Telecom
  - Router/Set-Top Box
  - Base Station
- Industrial
- Medical

Semiconductor Device

- Advanced Packaging
  - WLP (Fan in, Fan out)
  - SIP
  - Embedded
  - 3D Packaging
- Imaging
  - Infrared
  - Visible
- Integrated Circuit
  - ASIC
  - SOC
  - MPU/GPU/MCU/DSP
- MEMS & Sensors
  - Inertial Sensor
  - Environmental Sensor
  - Fingerprint Sensor
  - Oscillator
  - Microphone
  - Inkjet
  - RF MEMS
  - Light / Optics
- Memory
  - NAND
  - DRAM
  - Emerging
- Power Electronics
  - Discrete
  - Module
  - Compound (GaN, SiC)
  - Power RF
- RF
  - Radar
  - Filter
  - Module (FEM, W-Fi, BT)
  - Power Amplifier
- Solid State Lighting
  - LED
  - Laser / VCSEL
- Photonics
Business Model

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  o Contact

Monitor
1 per year quarterly updated

Teardown Track
205+ teardowns per year

Report
60+ per year

Custom Analysis
150 custom analyses per year

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5 process-based and 3 parametric costing tools

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On demand
Worldwide Presence

100+ collaborators in 8 different countries

Headquarters
› Nantes – System Plus Consulting
› Lyon – Yole Développement
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