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# TRIPLE CAMERAS: ARE THREE BETTER THAN TWO?

Corephotonics *White Paper*

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## Introduction

**While dual camera smartphones are becoming commoditized, the first few triple camera harbingers are on the horizon, starting with Huawei's P20 Pro just launched this week. Challenges and rewards are explained, several configurations are analyzed.**

In the past two years we have witnessed mass market adoption of dual camera technologies in most smartphone segments, across almost all manufacturers. We have seen dual cameras adopted both front and back, in various configurations for various end goals. Recent market reports indicate that 30% of smartphones in 2018 will use dual camera technologies, growing to 50% next year. Even though it took the smartphone market more than ten years to add a second camera, it seems that the addition of a third camera is just around the corner, within two years from the adoption of the second camera.

In this article, we will discuss some motivations for adding a third camera to the smartphone imaging complex, the challenges it brings and some possible solutions.

## The Road to Dual Cameras

The thickness of smartphone cameras has always been a challenge for mobile photography. The aperture size is tiny, the pixel size gets smaller and smaller as technology advances, and auto-focus and image stabilization are still required to fit in. Until recently, smartphone OEMs were scrambling to achieve decent low-light performance, high resolution, and low SNR, even while zooming in, at a 6mm camera height.

Dual camera technologies came to the rescue and challenged the camera module manufactures and smartphone OEMs with the following approach: If a single camera reached its full potential, why not synthesize the outputs of two cameras, so that each one can contribute its particular advantage?

The early days of dual camera smartphones started with the launch of the HTC One (M8), the first smartphone to utilize two rear cameras, with the sole purpose of enabling depth and focus effects on the resulting image.

This first phase of dual cameras continued until mid-2016, while various OEMs were testing dual camera technologies in some of their flagship smartphones, using different dual camera setups, including depth-only, RGB-Mono and Wide-and-Wider duos. There was still no "killer camera app" identified, nor a winning dual camera configuration.

In September 2016, Apple introduced the iPhone 7 Plus using a rear dual camera. Apple managed to shine the spotlight on a specific dual camera configuration, Wide+Tele, as the premium camera setup, and highlighted two photography features as the most-wanted by consumers: optical zoom and digital bokeh (or "portrait mode"). Since then, the dual camera smartphone domain took shape, whereby premium and flagship handsets use similar duos, while mid- to low-end models enable depth-only features.


*Zoom dual camera system introduced by Corephotonics in 2014, allowing true optical zoom without sacrificing the camera Z-height.*

## And Then There Were Three

Although dual camera smartphones have become a commodity in the high-end market segment, there are still new dual camera topologies that will make their debut in the very near future, in order to further enhance today's dual camera performance. One example of the next generation of dual camera evolution that is just around the corner is the use of folded camera architecture, that can not only dramatically improve the zoom factor and low light performance, but also allow even lower camera module height for a thinner handset device. An early prototype of this technology, a 5X zoom smartphone, was made public by OPPO in 2017.

Another interesting gradient in the smartphone camera evolution could be the use of a triple camera complex. Easier said than done, the addition of that third camera carries significant challenges (and rewards), while opening up a wide array of possibilities and configurations for smartphone manufacturers .

*Triple cameras come in various forms and configurations*

Next, we will review three main challenges that such triple camera systems bring about.

## Challenge 1: “Real-Estate” & Cost

Three camera solutions increase the bill of materials (BoM) of the camera system along with occupying further space at the expense of other technologies that could be integrated into the mobile device (e.g. IR sensing, proximity sensor, structured light, larger battery, etc.).

This penalty is almost inevitable, but OEMs will have to weigh it against total value for money, depending in part on their target audience's priorities. The added cost of the third camera directly depends on the camera configuration, as explained later in this article, and could be anywhere between $10 to $30.

## Challenge 2: Calibration

In order to achieve a seamless user experience in video/preview and avoid artifacts or long processing times during image fusion or bokeh, the camera has to be carefully calibrated for both intrinsic and extrinsic properties of the triple aperture imaging system. This calibration must be done as part of the camera manufacturing line, in a meticulous way and possibly even continuously and autonomously performed to compensate for physical dynamic changes such as temperature variances and device-drop impact.

Camera system calibration and frame-to-frame synchronization are adding a challenge for camera module makers as well as for OEMs in this more complex camera system. In case all three cameras need to be perfectly calibrated one with respect to the others, the camera assembly process must be carefully designed, and the expected yield would be lower. In turn, these have direct effect on the total camera cost.

## Challenge 3: Firmware, Algorithms, Power

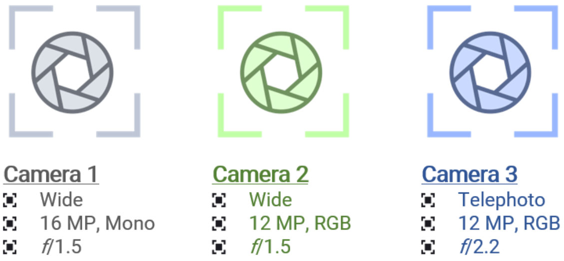
A triple camera system mandates more complexity on the firmware side as well. The new framework will have to deal with three cameras that should operate as one. Processes like power management, frame request, memory management and other state-machines within the camera manager, will have to deal with more logic, more data and allow more parallel processing in the pipeline while serving the application level in more efficient ways to meet real-time performance .

Algorithms, on the other hand, have similar challenges. These include assuring reasonable processing run time and allowing zero image quality artifacts resulting from multiple inputs from multiple cameras, all while dealing with inaccuracies of frame-to-frame synchronization, occlusions, and flaws in the triple camera calibration data .

As a result of these complexities, power consumption for the overall system (cameras + processing platform) of this configuration could be greatly affected.

Next, we will suggest several tri-aperture camera configurations. Obviously, these are specific examples representing a family of trios, each with its own pros and cons, while many other configurations are possible.

# Trio 1: Zoom camera for low-light photography




| Camera I | Camera II | Camera III |
|---|---|---|
| Wide camera, 24mm focal length (35mm equivalent) | Wide camera, 24mm focal length (35mm equivalent) | Telephoto camera with 72mm focal length (35mm equivalent) |
| 16 mega pixel monochrome, small pixel | 12 mega pixel RGB, large pixel | 12 mega pixel RGB, small pixel |
| f-number of *f*/1.5 | f-number of *f*/1.5 | f-number of *f*/2.2 |
| OIS | OIS | OIS |

This camera will allow the user to take pictures in a relatively dark scene, but not at the expense of having decent zoom capabilities. A good example use case would be taking photos of a concert stage, a tough scene that requires both zoom and low-light capabilities.

**The continuous zoom capability originates from the following:**

I. The monochromatic camera (Camera I) can offer more diagonal resolution just by not using the Bayer filter array that is typically placed over the sensor pixels in a color camera. In this system the color reproduction can be achieved using the color cameras (Cameras II and III).

II. The different spatial sampling size (i.e., pixel size) of the mono wide camera versus the color wide camera (Cameras I and II), will also contribute to the overall magnification power of this subsystem dual camera.

III. The third camera will allow even further center resolution that originates from its telephoto lens.

The enhanced low light performance originates from the relatively low f/# of all three cameras involved. Fusing the color camera output frame (Camera II) with the monochromatic camera output frame (Camera I) that gains twice as much light as the former, can also improve SNR dramatically. This two-times gain in light exposure is a result of not using a color filter array in which each pixel is filtered to record only one of three colors at the expense of the total potential light absorption.

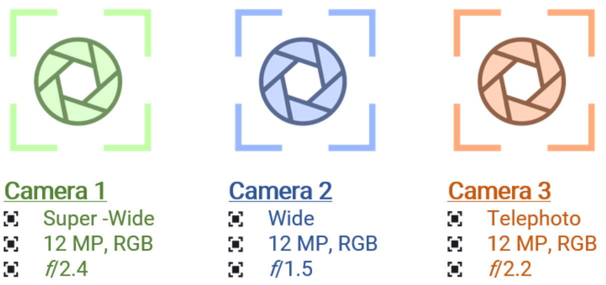

*RGB/Mono/Tele triple camera gains better light sensitivity and optical zoom*

Another obvious advantage of this suggested configuration versus existing zoom dual cameras is the large overlapping field of view (FoV) between Cameras I and II. This feature allows stereo depth sensing in the entire wide FoV for various applications like augmented reality as well as digital bokeh (shallow depth of field effect).

The obvious disadvantage of such a power regime can appear in the form of a relatively high shutter lag during still capture and no improved low light performance during video recording. Also, it is important to carefully monitor power consumption of such a camera system, avoiding an unleashed power consumption from three cameras streaming concurrently.

Camera order has an impact on system performance. For example, placing the wide color camera in the middle allows smoother transition from the wide to tele cameras during video recording as well as simplifies the fusion process between two neighboring cameras (color and mono). This arrangement will come at the expense of stereo depth sensing accuracy that could be improved by placing the wide color camera and the wide mono camera at opposite ends.

## Trio 2: FishEye zoom camera: From ultra-wide-angle camera to telephoto zoom



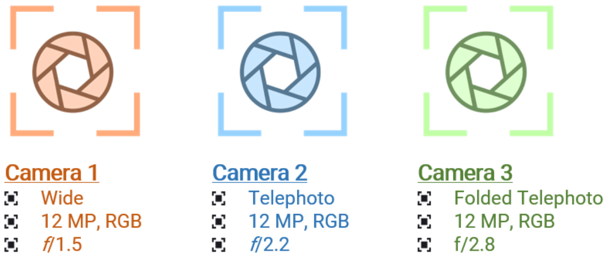

| Camera I | Camera II | Camera III |
|---|---|---|
| Super-wide camera, 135 degrees | Wide camera, 24mm focal length (35mm equivalent) | Telephoto camera with 72mm focal length (35mm equivalent) |
| 12 mega pixel RGB, small pixel | 12 mega pixel RGB, large pixel | 12 mega pixel RGB, small pixel |
| f-number of *f*/2.4 | f-number of *f*/1.5 | f-number of *f*/2.2 |
| Fixed focus | OIS | OIS |

This camera could be very suitable for travel enthusiasts. For example, in the case of capturing an open landscape, the super-wide-angle lens avoids the typical panorama stitching capture mode. At the same time, being able to capture fine details while zooming is exceedingly useful. With today’s smartphones, users must decide if they prefer high-quality optical zoom ability or super-wide images; not so with this triple camera configuration.

In contrast to the previous triple camera system, this trio configuration can handle power consumption more economically as most of the time there will be only one active camera, per user zoom factor. Also, the logic behind the camera array order is more straightforward as there will always be seamlessly switching between neighboring cameras in a consecutive manner according to the camera magnification power.

The challenges of this system relate to the relatively high lens distortion of the super-wide camera while applying video smooth transition, fusion of two images or even factory calibration process. In addition, photography-avid mobile users would highly appreciate a longer focal length for the tele camera, allowing them to get a much better close-up on the target object even from afar.

## Trio 3: Super zoom with excellent low-light: 5x optical zoom, 25x total zoom, 5x more light (compared to single aperture)




| Camera I | Camera II | Camera III |
|---|---|---|
| Wide camera, 24mm focal length (35mm equivalent) | Telephoto camera with 60mm focal length (35mm equivalent) | 5x optical zoom with 125mm focal length (35mm equivalent) |
| 12 mega pixel RGB, large pixel | 12 mega pixel RGB, small pixel | 12 mega pixel RGB, small pixel |
| f-number of *f*/1.5 | f-number of *f*/2.2 | f-number of *f*/2.8 |
| OIS | OIS | Folded camera with OIS |

This triple camera will allow the user to enjoy unprecedented optical magnification of 5x true optical zoom, without compromising today's smartphone form-factor (i.e. camera thickness of 5mm that can coexists with a bezel-less display). Despite the relatively high F/# (i.e., f/2.8), the tele camera low light performance will be phenomenal because of the folded tele camera entrance pupil that will allow five times more light than a standard RGB wide camera, and over 2.5 times more light compared to the above-mentioned wide camera in this configuration.

Such a super-zoom triple camera will offer a seamless, continuous zoom experience at any desired zoom factor from 1x to 5x at still capture and 4K video recording. Combined with multi-frame technologies, image fusion and multi-scaling, this camera could provide up to a total of 25x zoom factor.


*Wide / 2x Telephoto / 5x Telephoto*

This state-of-the-art tri-aperture system, enabled by [folded zoom optics] and [folded OIS] technologies, is outstanding in that it fully addresses the two fundamental drawbacks of today's smartphone photography: low light performance and lack of significant optical zoom.

## Summary

In this article we reviewed three key challenges for triple cameras, and three specific configurations that represent a wide variety of triple camera setups, which might soon be adopted by OEMs.

In general, the law of diminishing returns aptly applies to multi-aperture technologies. The second camera in dual setups offers the greatest returns in terms of added user experience, while the third camera in any triple setup would need to provide significant added value to the overall user experience in order to justify its additional cost, size and complexity. Triple camera configurations that adequately resolve low-light performance limitations (both capture and video modes) as well as proper optical zoom capabilities (beyond 3x) would make most sense to OEMs in the near future.

## Corephotonics Ltd.

Corephotonics is the pioneer and worldwide market leader of multi-aperture camera technologies for mobile devices. Corephotonics' primary mission is to **perfect** the mobile camera photography experience and to provide **superior** image quality by combining our novel optics, mechanics and computational photography technologies.

Corephotonics' comprehensive technologies excel in addressing some of the most challenging deficits of existing smartphone cameras. We develop and deliver end-to-end multi-aperture solutions supporting the most professional photography capabilities, such as optical zoom, superb low-light performance, Bokeh and depth features, and optical image stabilization, all in an incredibly slim form factor. We partner with manufacturers at early design stages, matching each manufacturer's unique design and imaging requirements, and providing continuous support through commercialization and mass production.

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