Autofocus systems

Based on the series of articles in http://www.exclusivearchitecture.com/

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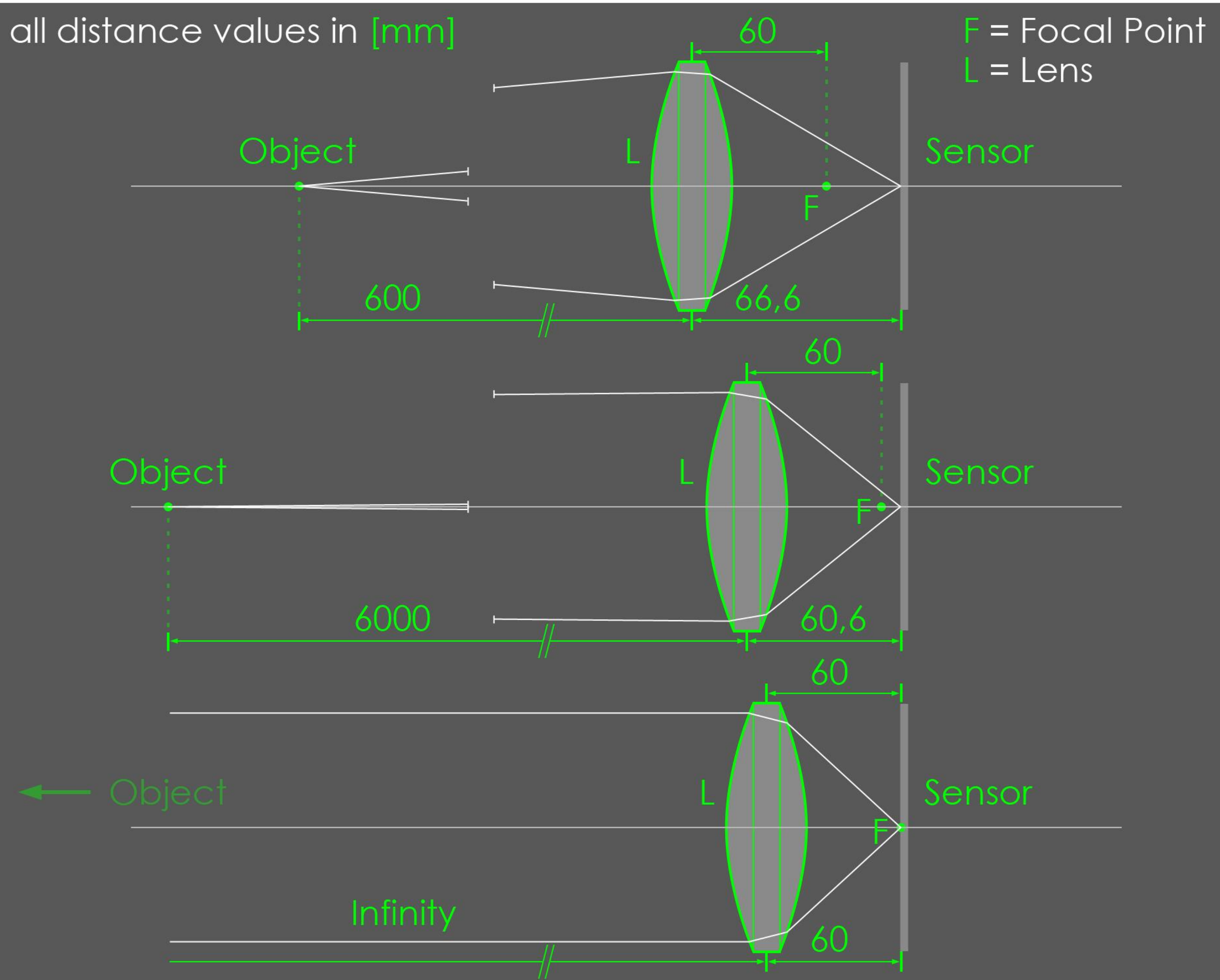
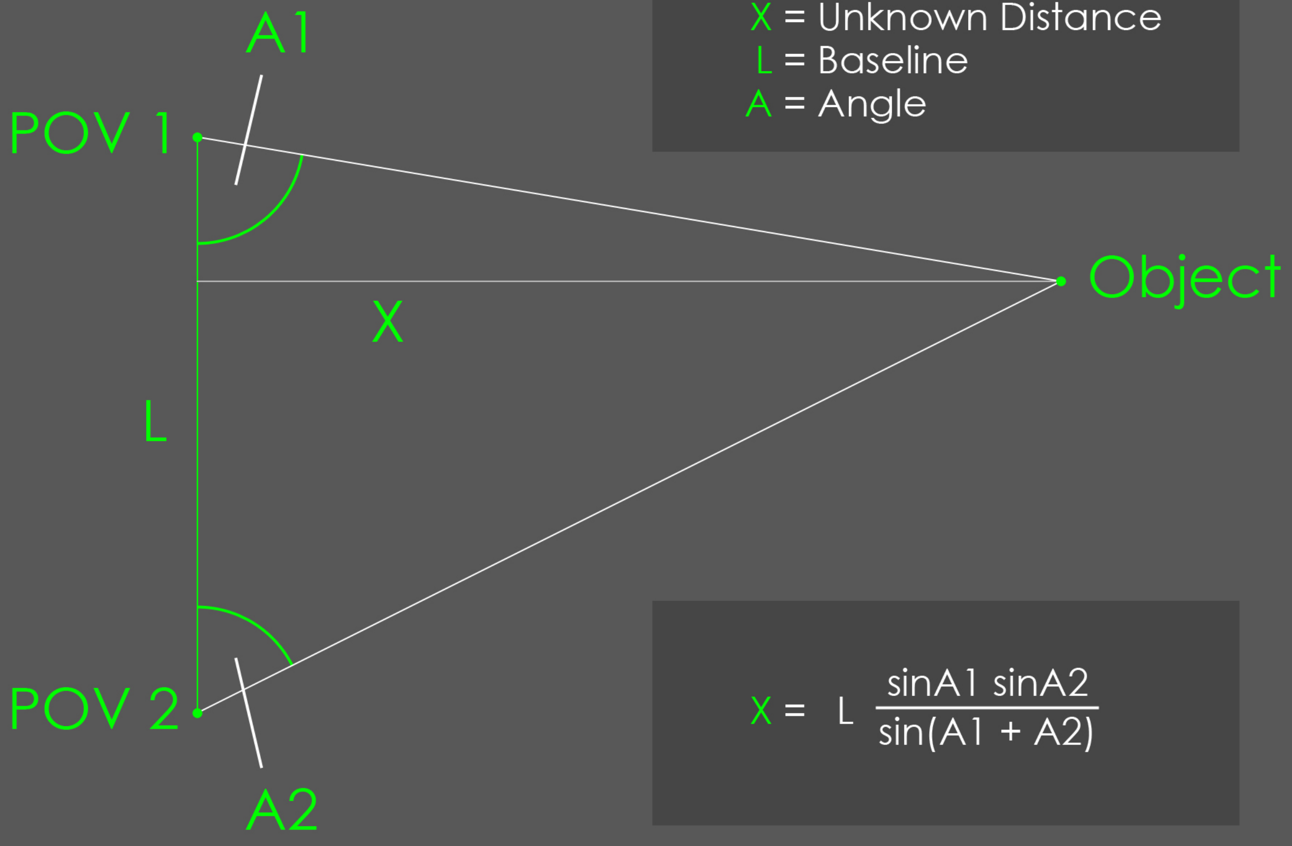
Focus Distances



The greater the distance is between the object and the camera, the closer the lens has to be moved towards the sensor in order to focus.

Triangulation - Two Variable Angles

POV = Point Of View
X = Unknown Distance
L = Baseline
A = Angle

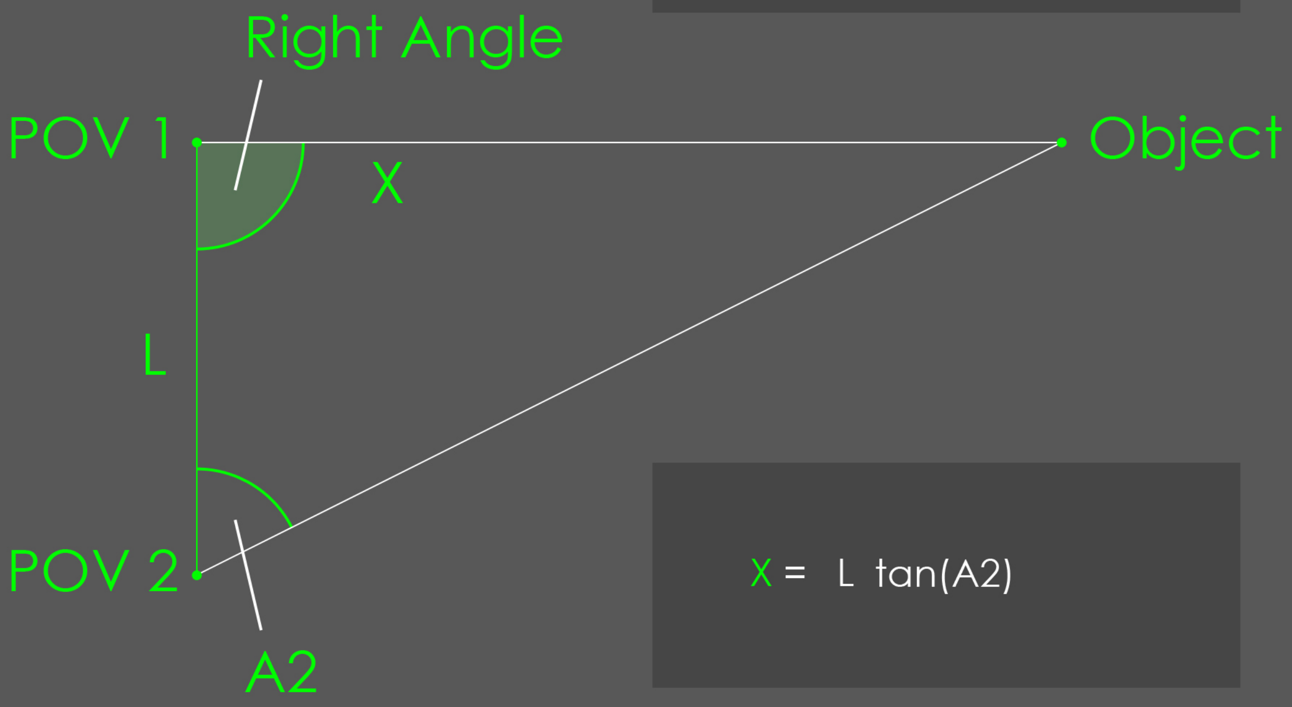


$$X = L \frac{\sin A1 \sin A2}{\sin(A1 + A2)}$$

Triangulation allows to determine an unknown distance by measuring the lenght of a baseline established by two points and two viewing angles.

Triangulation - One Variable Angle

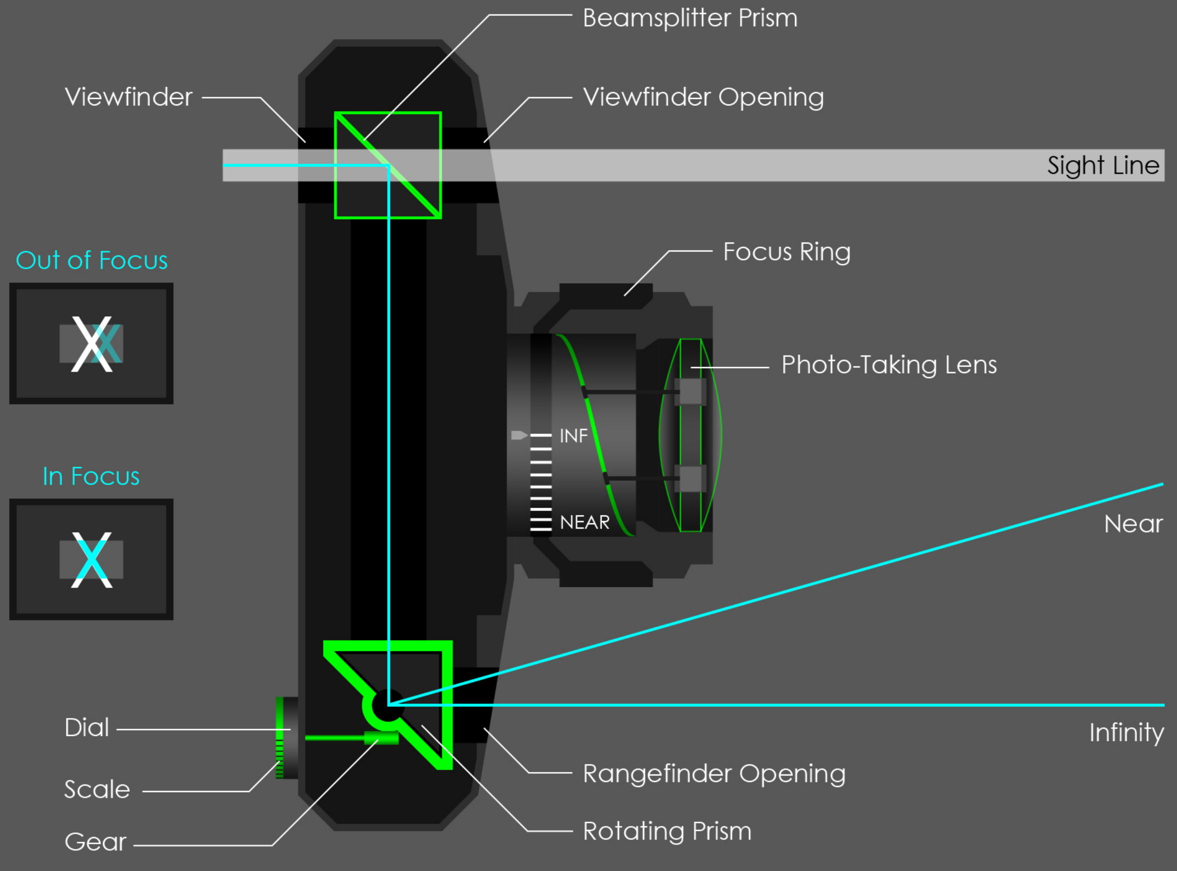
POV = Point Of View
X = Unknown Distance
L = Baseline
A = Angle



$$X = L \tan(A2)$$

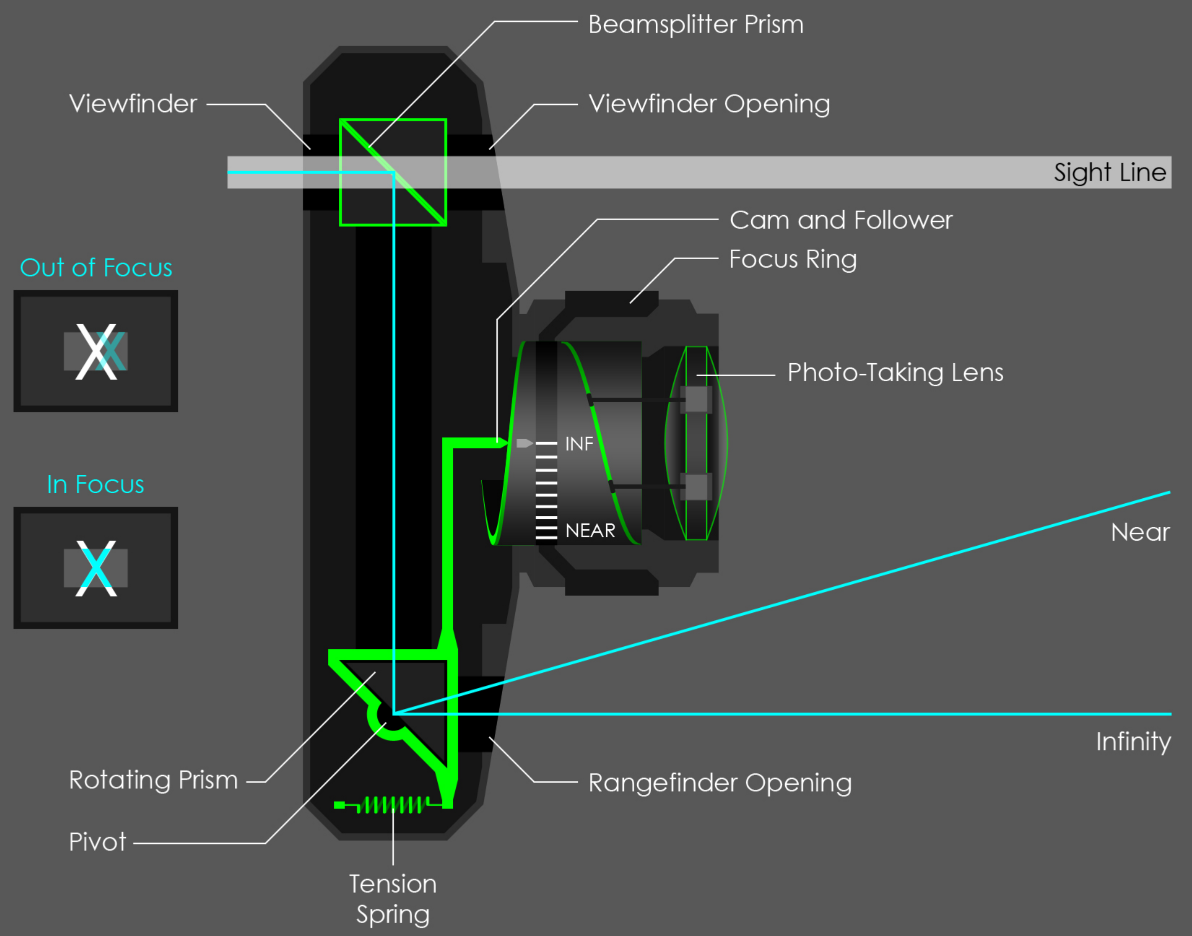
The right angle simplifies the calculation so that the unknown distance can be determined by knowing one angle and the lenght of the baseline.

Uncoupled Coincide Image Rangefinder



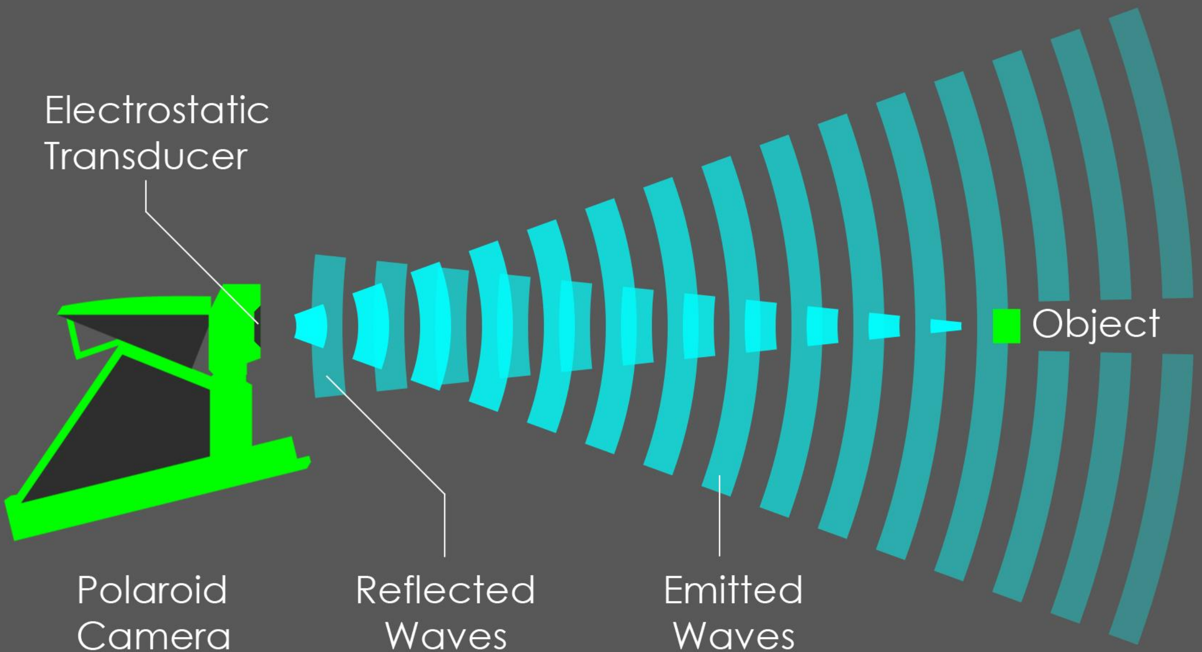
The rangefinder dial is turned until the two images coincide. The scale displays the target distance which is used to set the lens accordingly.

Coupled Coincide Image Rangefinder



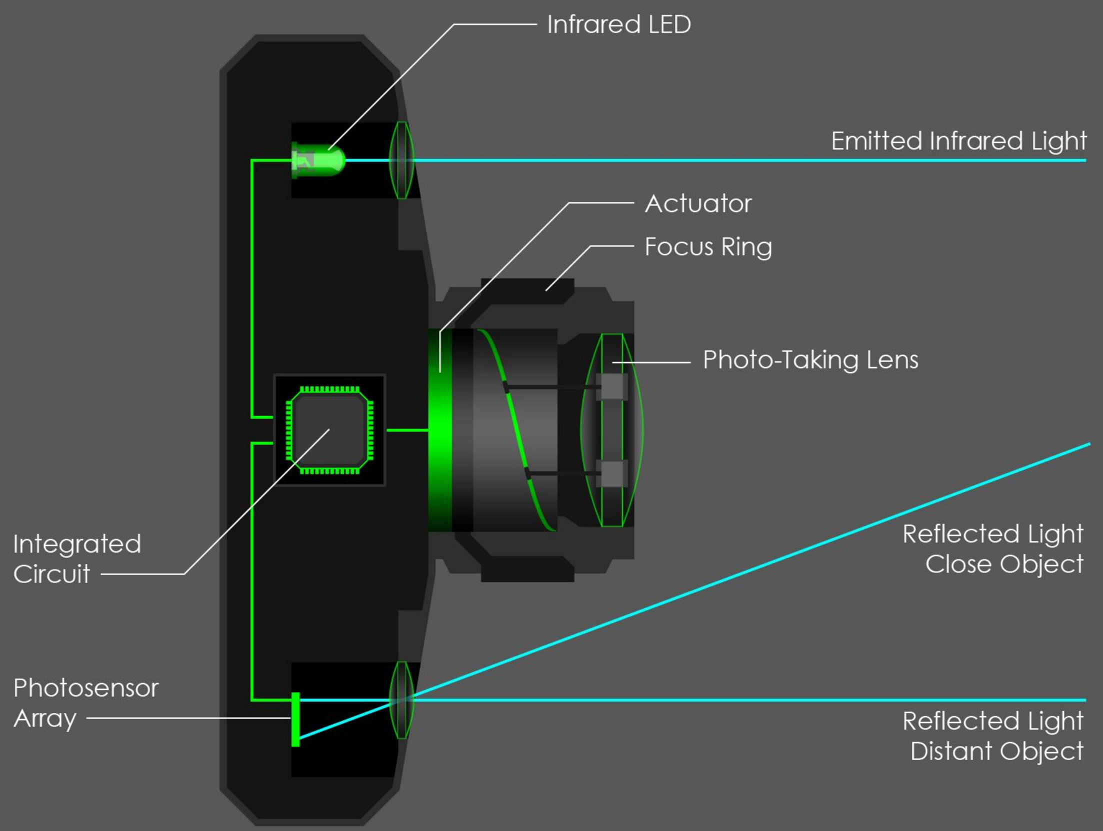
The lens position is coupled to the position of the pivoting mirror by a cam and follower mechanism. Turning the lens also turns the pivoting mirror.

Sonar System



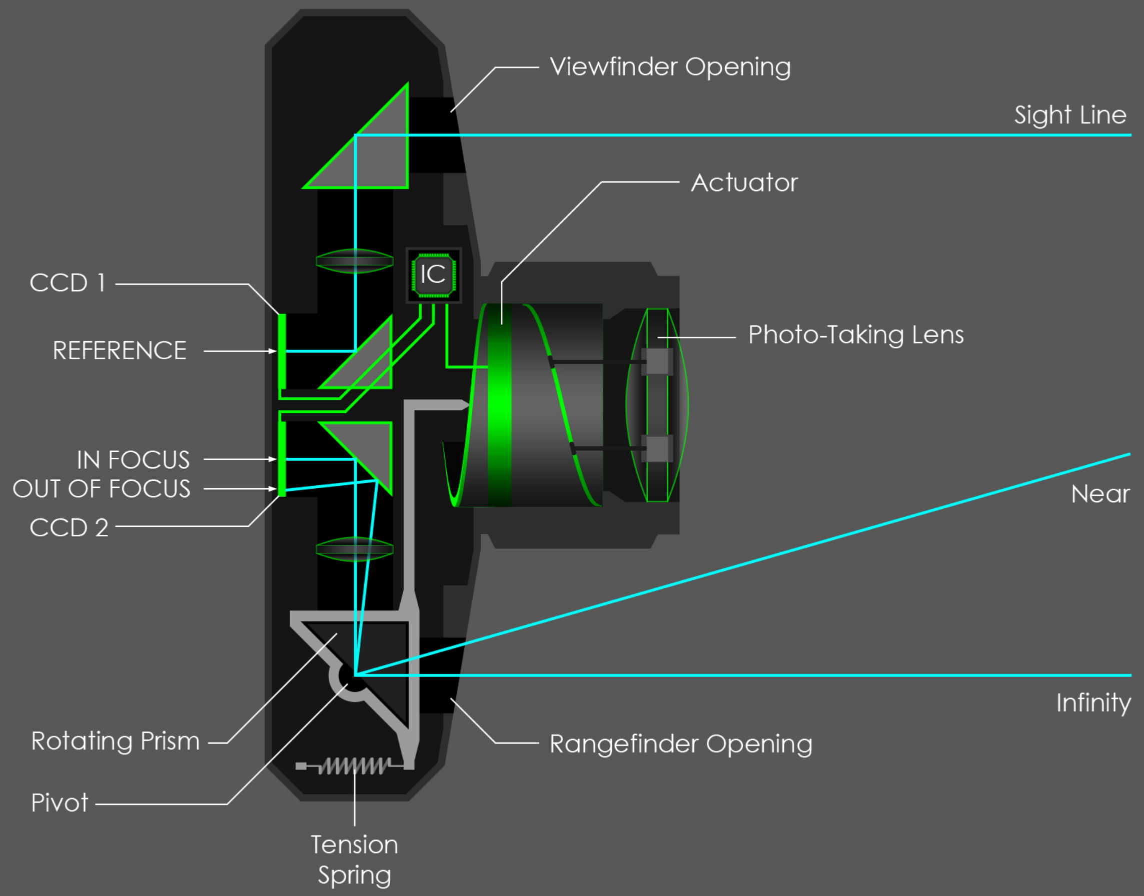
In the early 1970s, some polaroid cameras used an ultrasonic echo system to focus their lenses. The system worked for distances up to 10 meters.

Infrared Light Triangulation



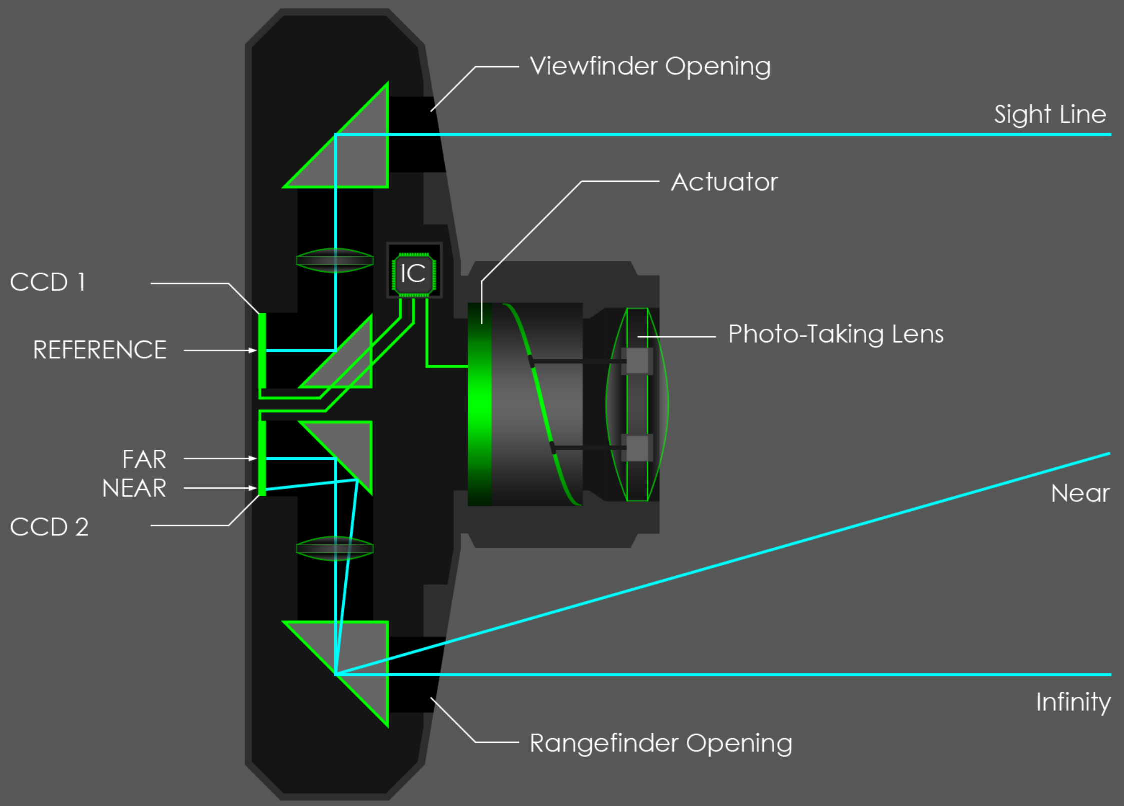
An infrared light emitting diode projects a spot on a target. An array of photosensors records the angle under which it finds this spot and an IC calculates the distance. Finally, an actuator is used to focus the lens.

CCD Triangulation



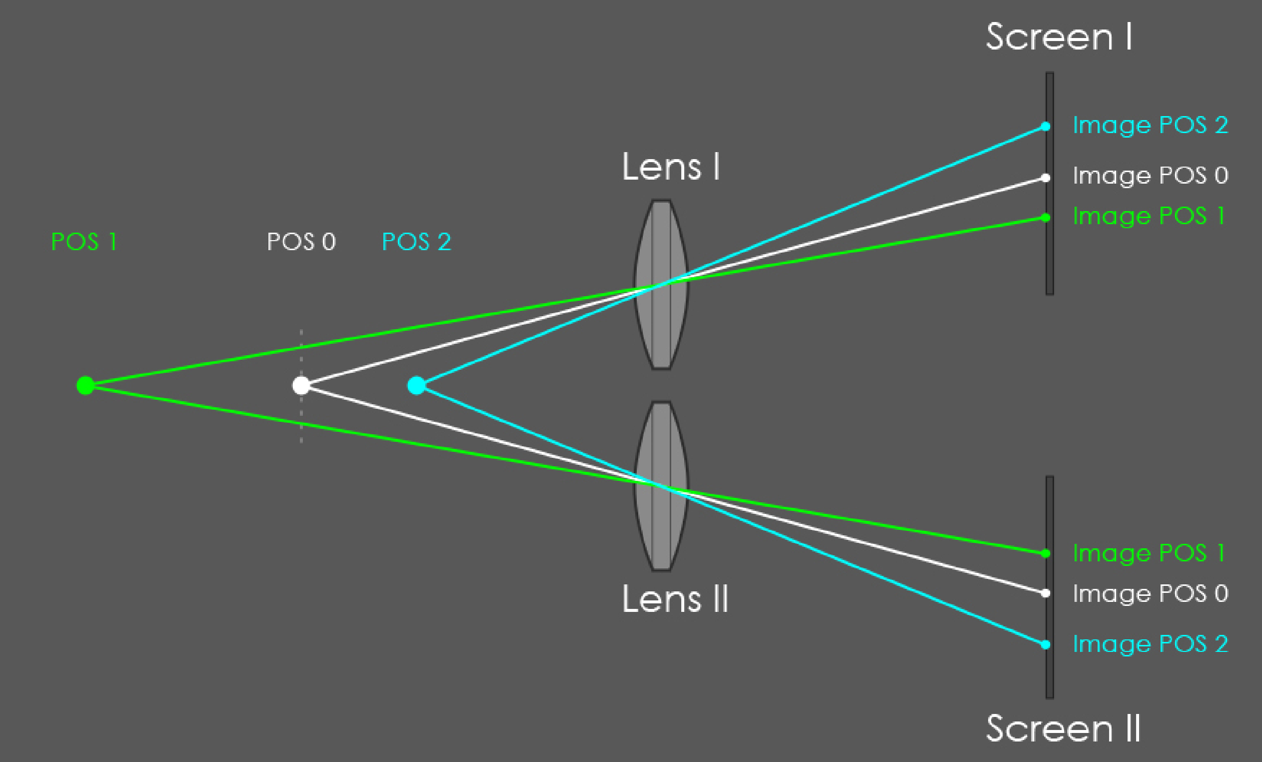
The actuator moves the lens until the projected image in CCD 2 is in the same relative position as the reference image in CCD 1. A comparator circuit stops the actuator once the phases are identical.

Solid State Triangulation



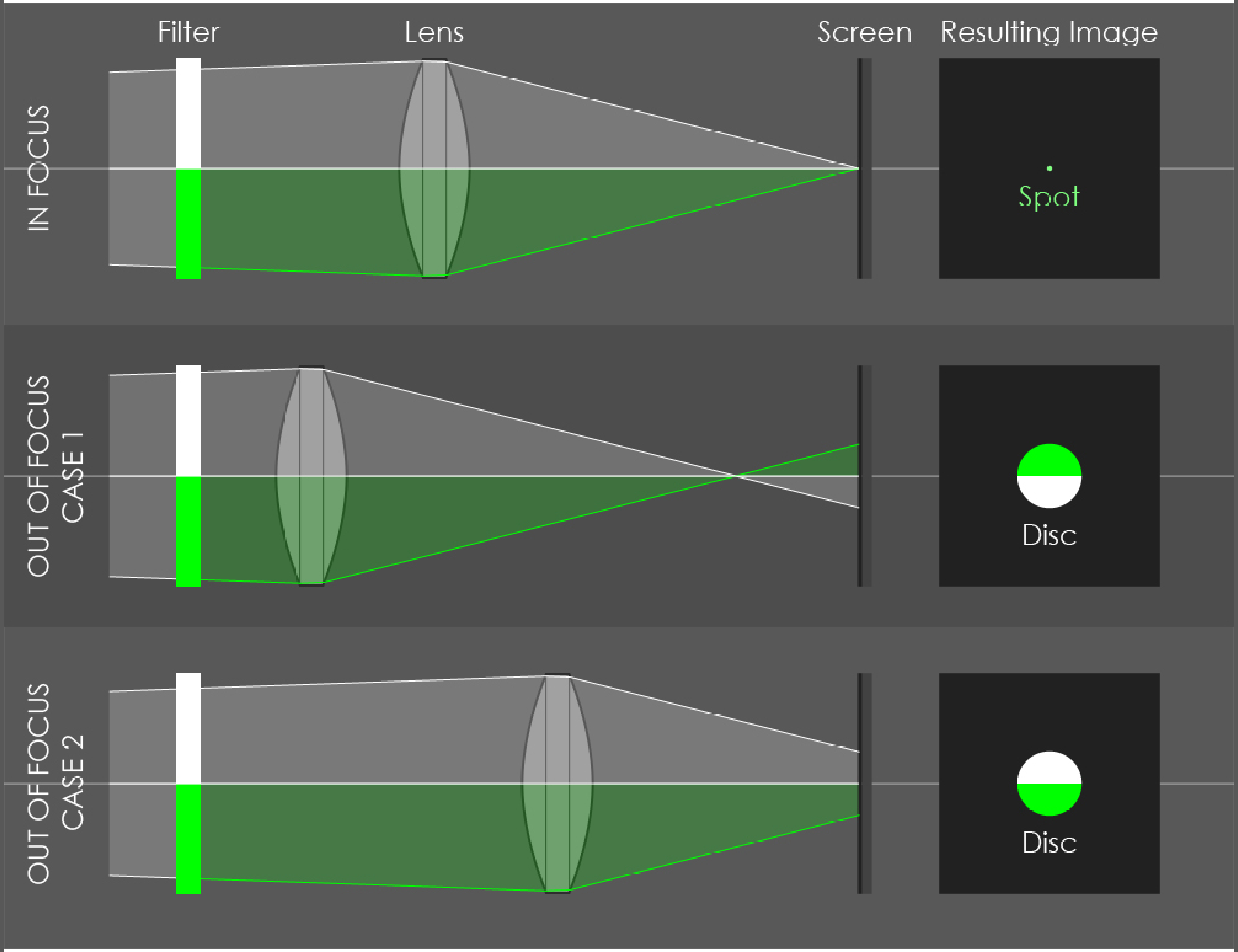
Solid Strate Triangulation detects the phase difference without a pivoting mirror. The integrated circuit is optimized to find the offset of both phases and drives the lens accordingly.

Simplified Phase Detection Principle



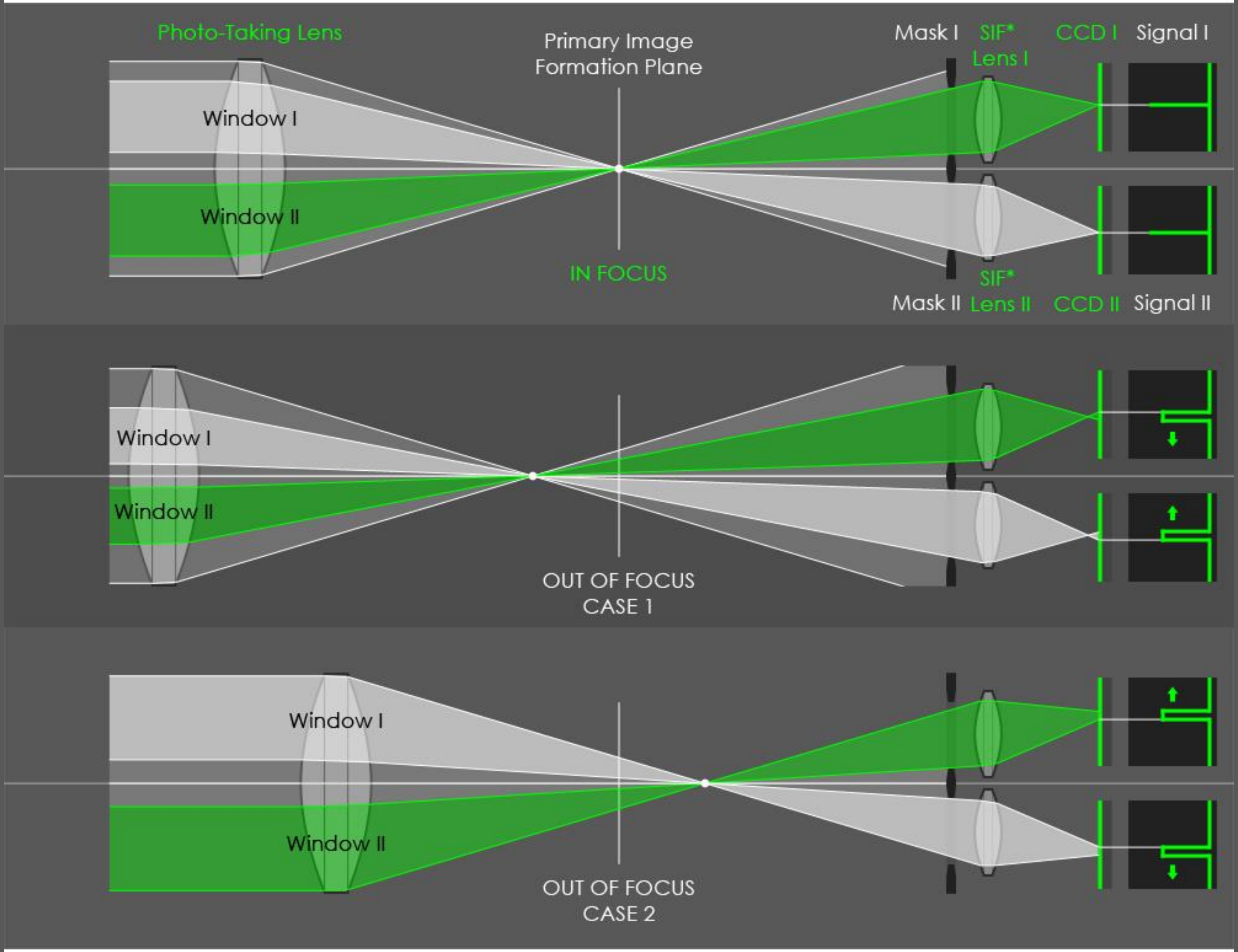
If the object point moves from position 0 to position 1, the image points move towards each other. If the object point moves to position 2, the image points move away from each other.

Visualization of individual halves of light rays



The scenes show a lens oriented towards a punctual light source. A filter is placed in front of the lens so that light rays from the upper half remain white and the lower half is colored green.

Phase Detection Principle

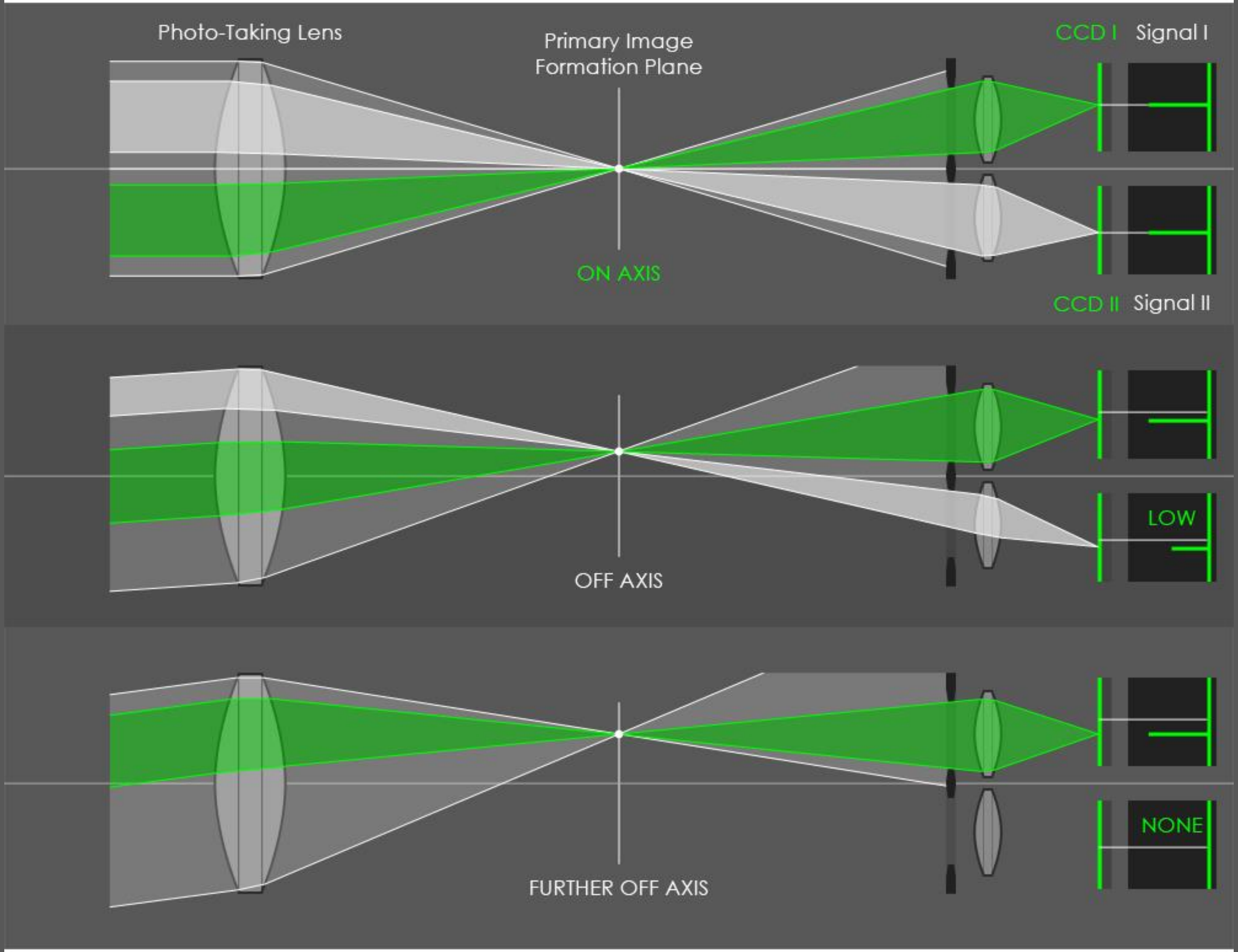


* SIF = Secondary Image Formation

Case I: The CCD sensors generate signals shifted towards each other.

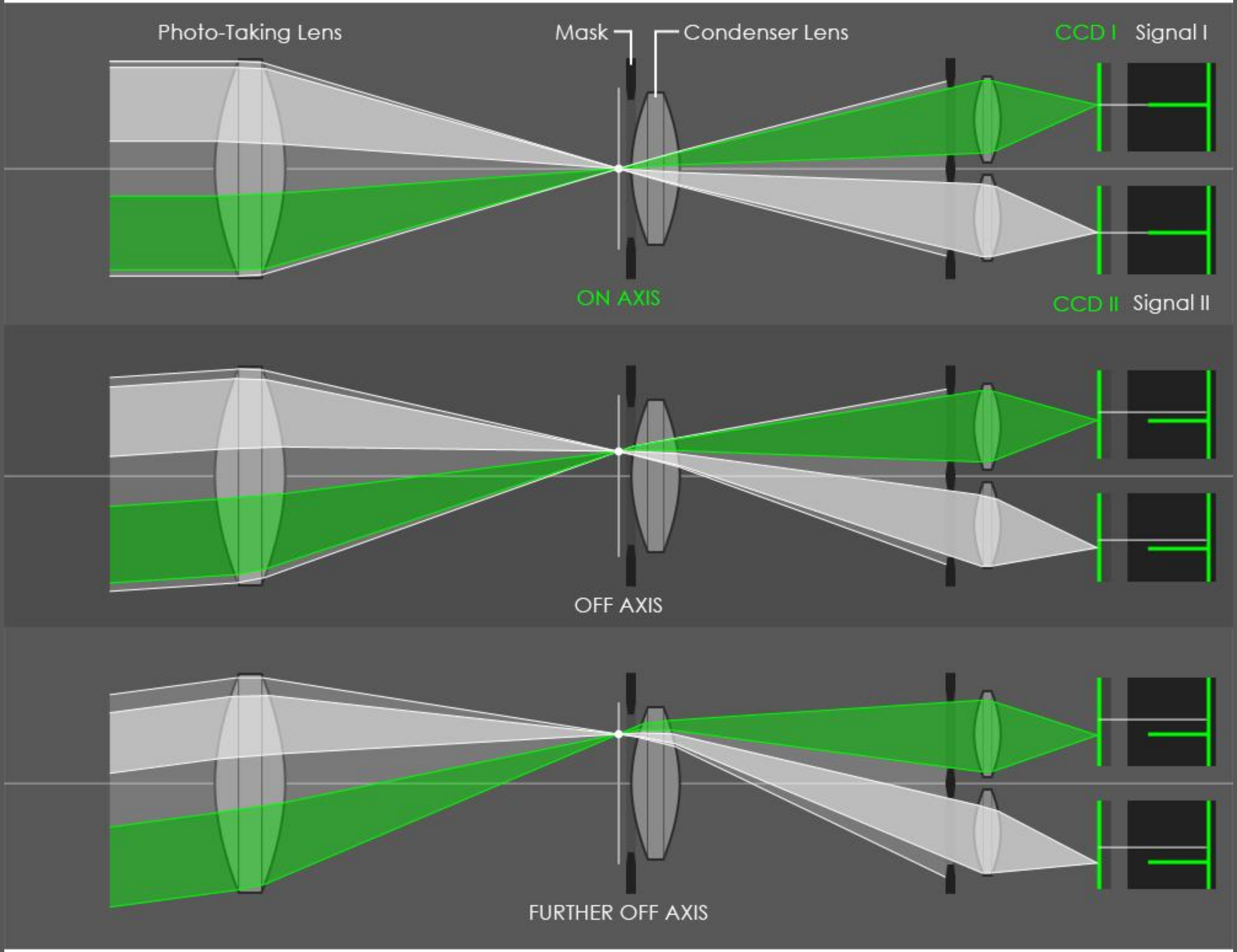
Case II: The CCD sensors generate signals shifted away from each other.

Off Axis Situations



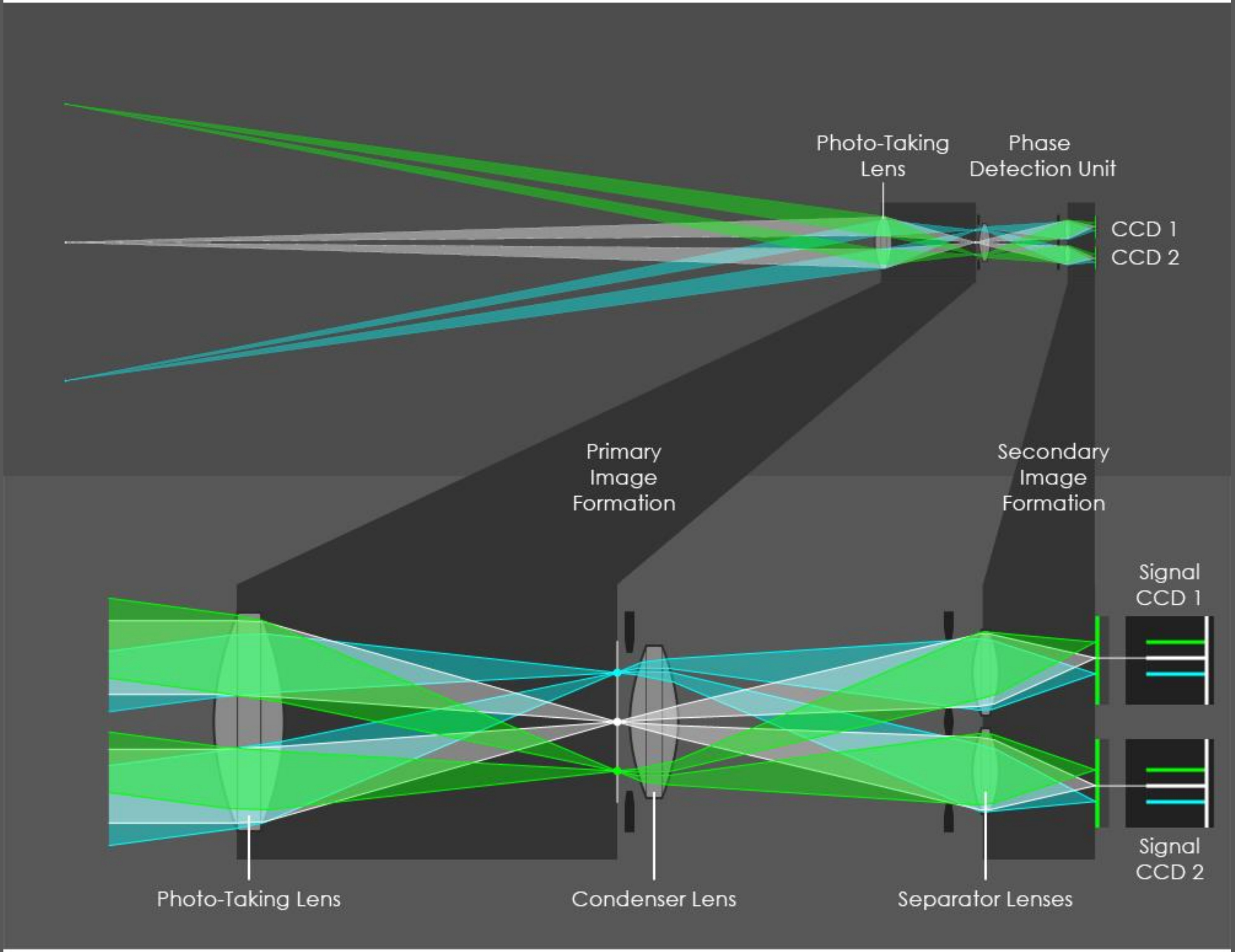
Case I: For the subject located off the optical axis, the brightness of the image received by CCD II is reduced. Case II: The subject is too far off the center, and CCD II receives no image at all.

The Role of the Condenser Lens (Field Lens)



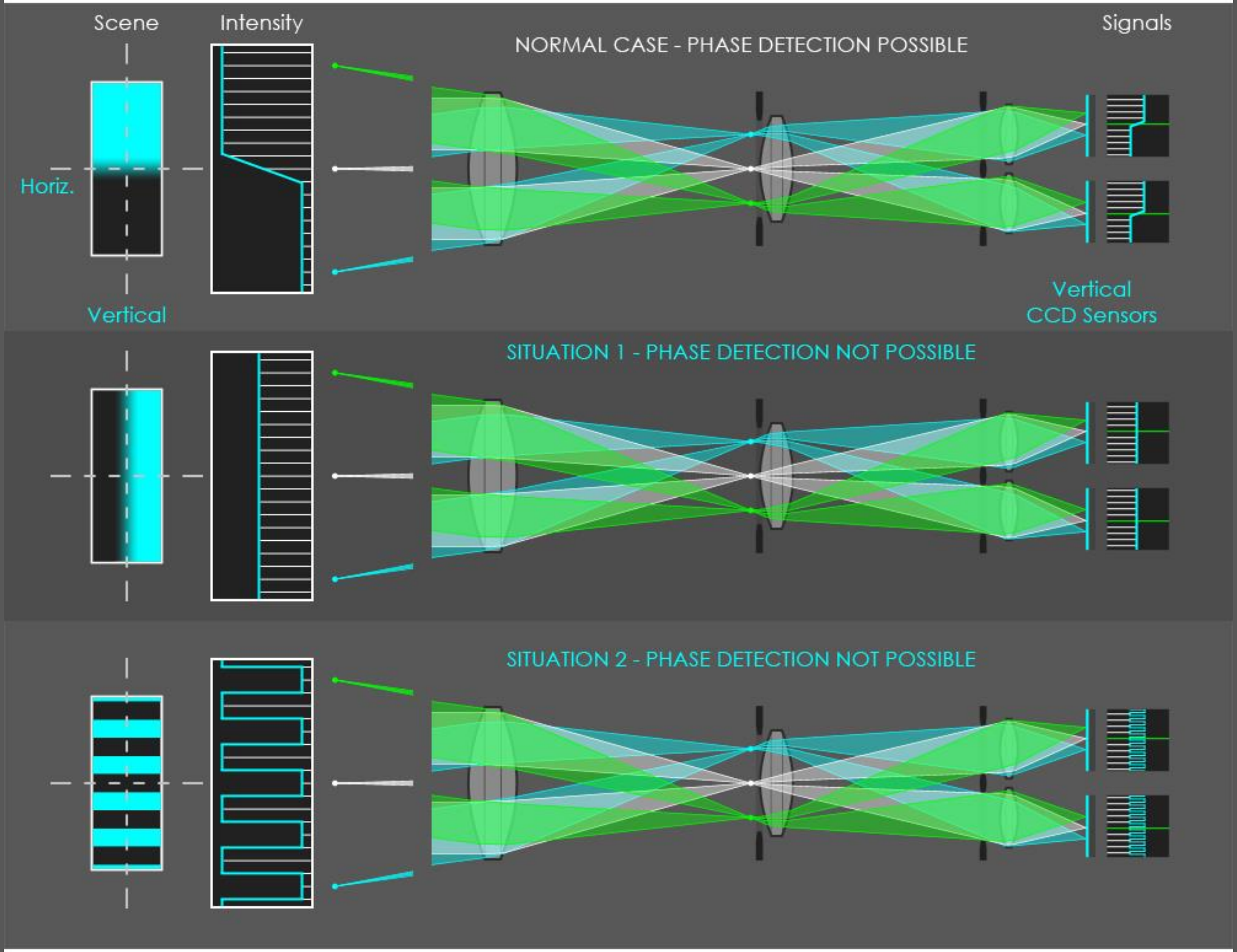
The condenser lens conjugates each secondary image formation lens with its dedicated window within the photo-taking lens. This allows the CCD sensors to capture light of those subjects further off the optical axis.

Phase Detection on Widespread Object



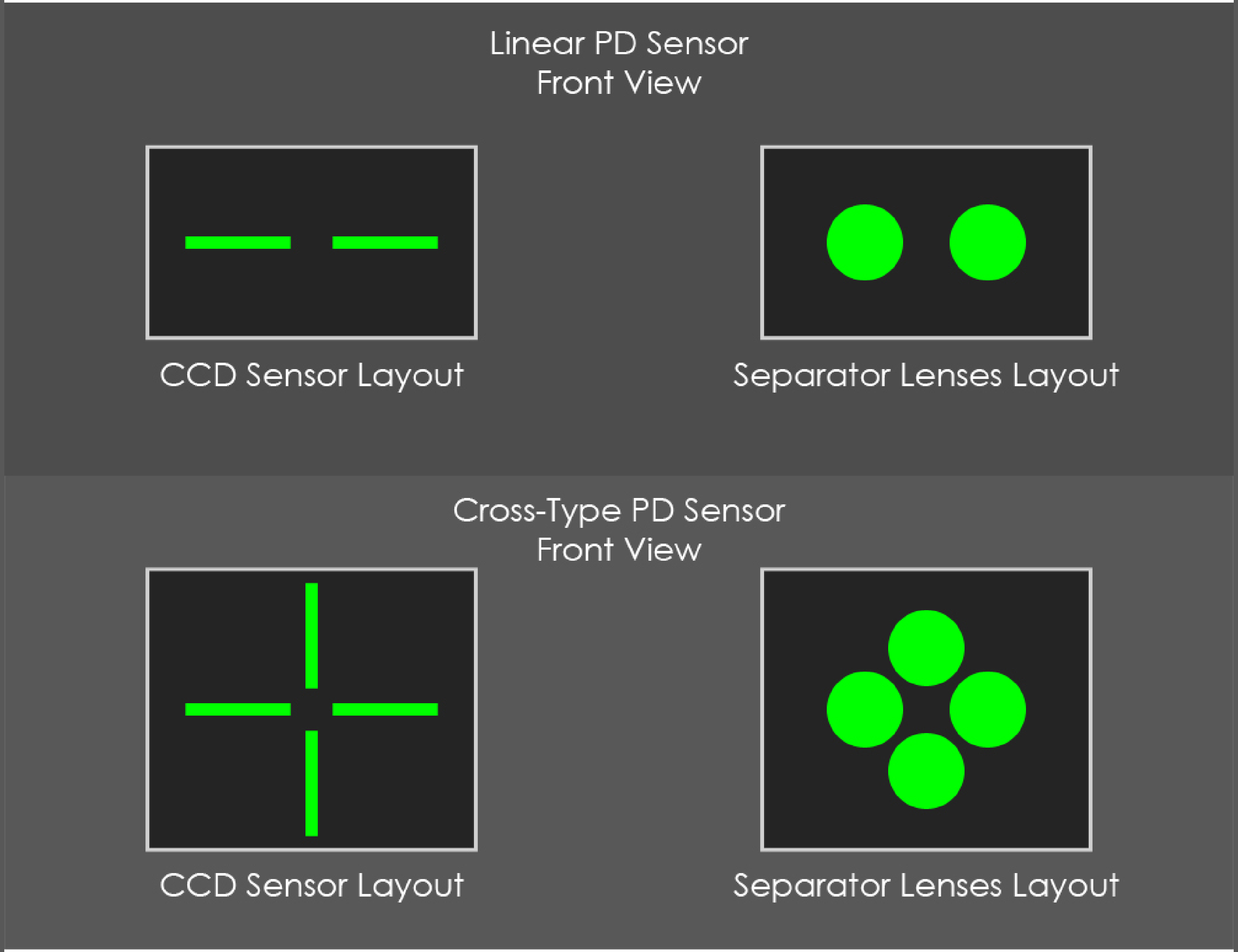
The figure shows the rays involved in phase-difference calculation for a widespread object, represented by three object points. The lower diagram is an enlarged view of the same configuration.

Problems of Linear PD Sensors



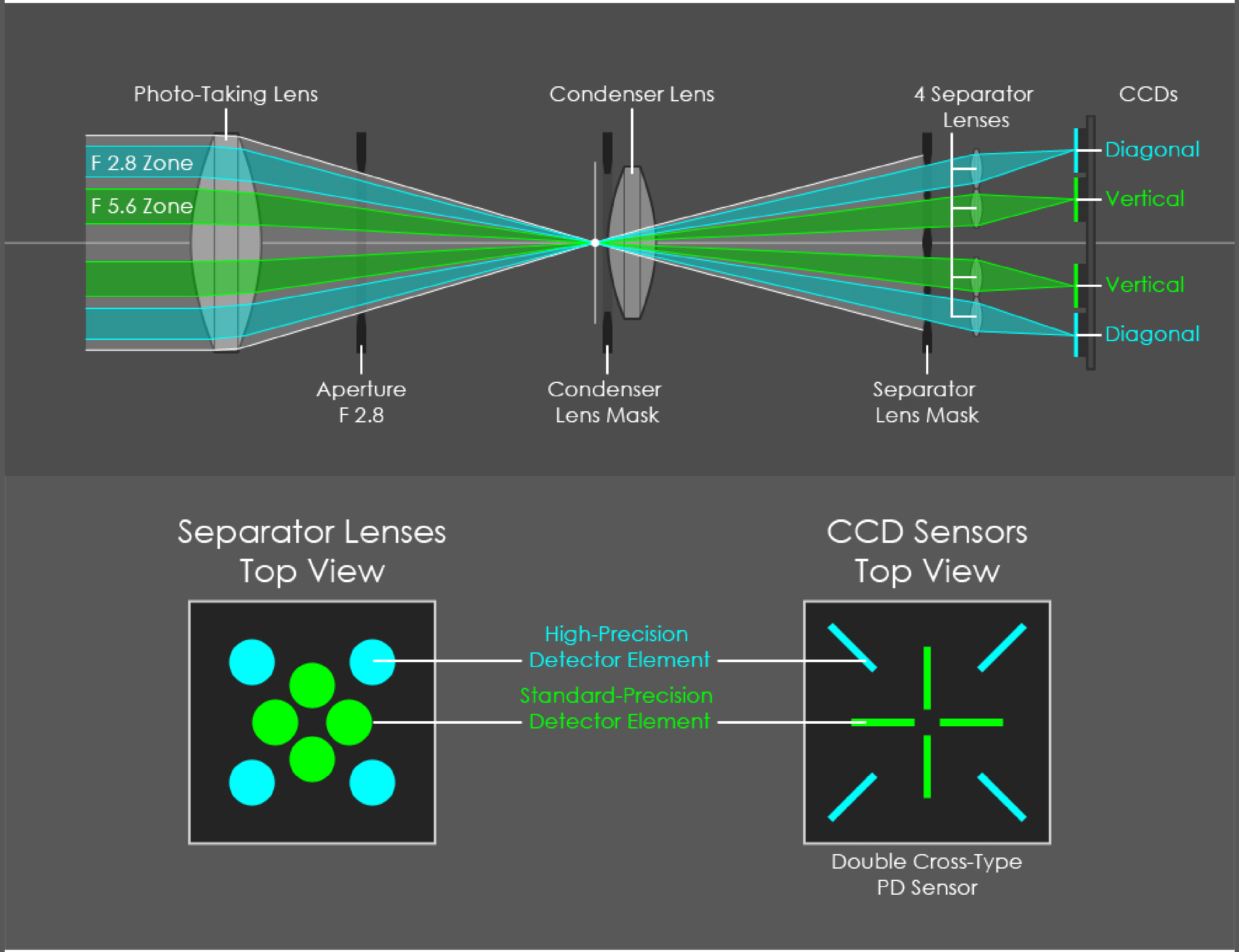
In a normal case, the phase detection system can determine coincidence of the images recorded on both CCD sensors. Conversely, situations 1 and 2 both lack unique features so that the phase difference cannot be found.

Types of PD Sensors



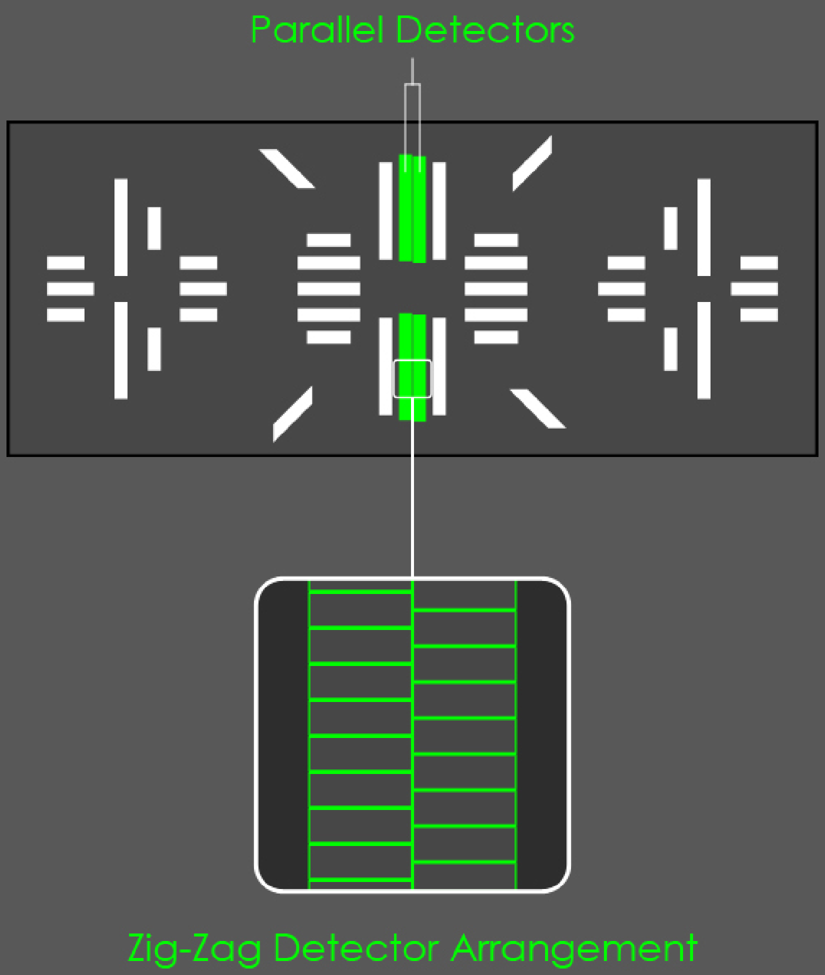
A linear phase detection sensor is only capable of detecting one-dimensional contrast edges. A cross-type sensor is a combination of two linear sensors so it can determine contrast edges in two dimensions.

High Precision AF Points



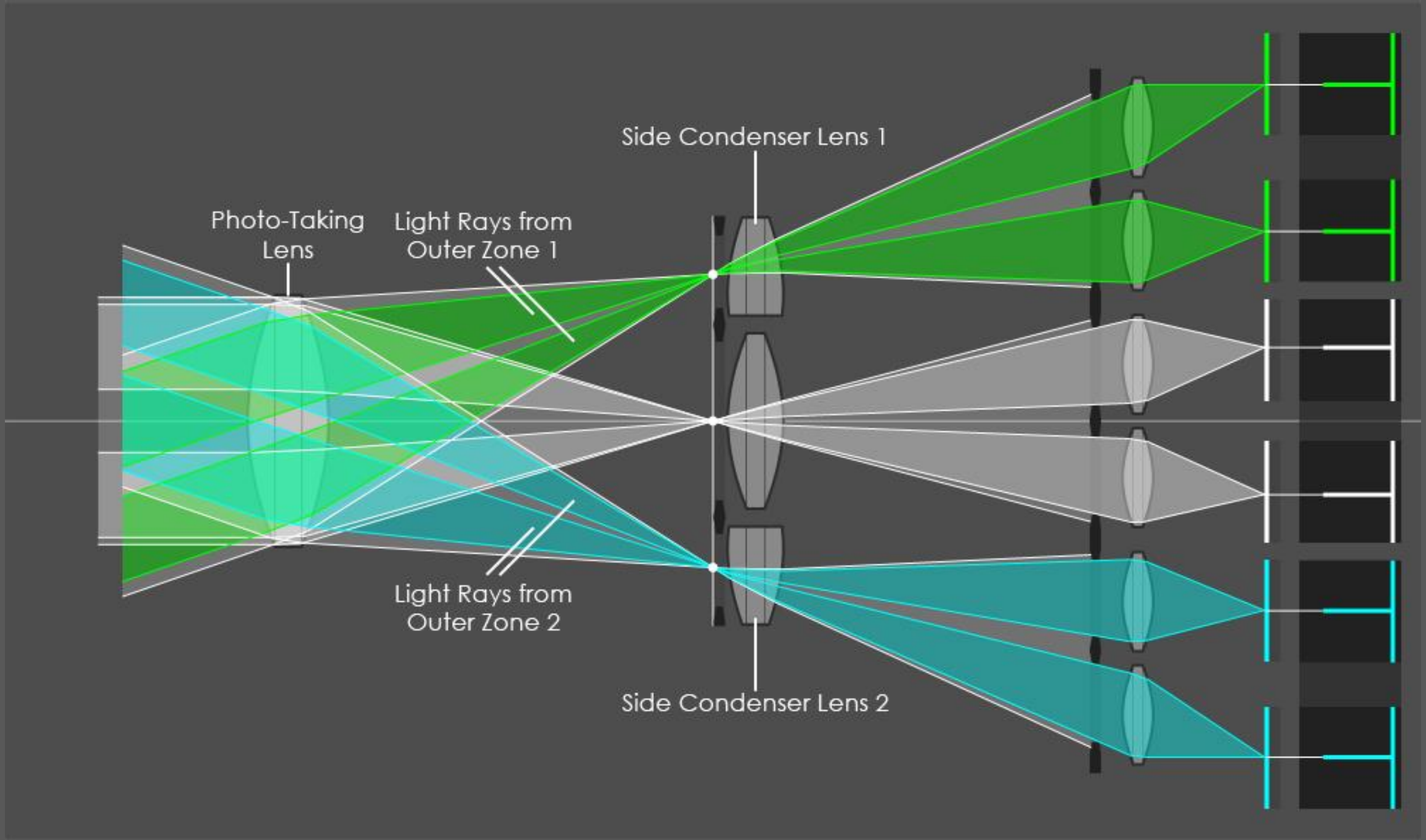
The high-precision CCD sensors are located further apart than the standard-precision detectors. Therefore, any change in the position of the primary image will result in larger phase-shifts on the diagonal CCDs.

Autofocus Sensor Design - Zig Zag Pattern



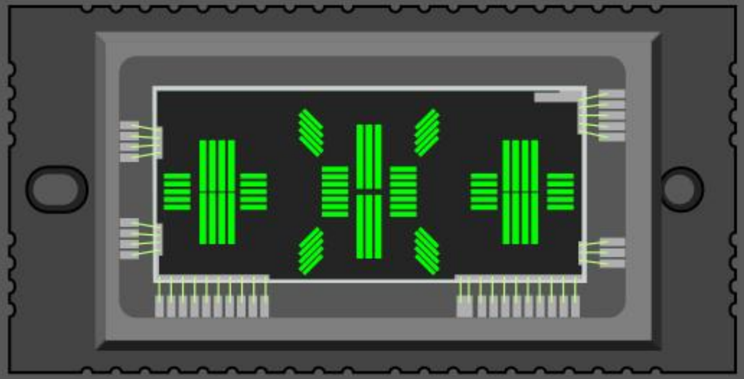
The zig-zag focusing pattern increases the resolution of the vertical line detectors for the center. The scheme shows the autofocus sensor layout of the Canon EOS 7D.

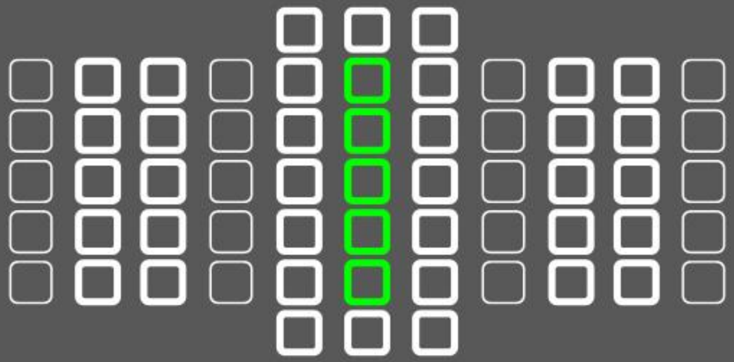
Autofocus Zones



The three condenser lenses create individual zones
that allow focusing on objects at the outer edges of the frame.

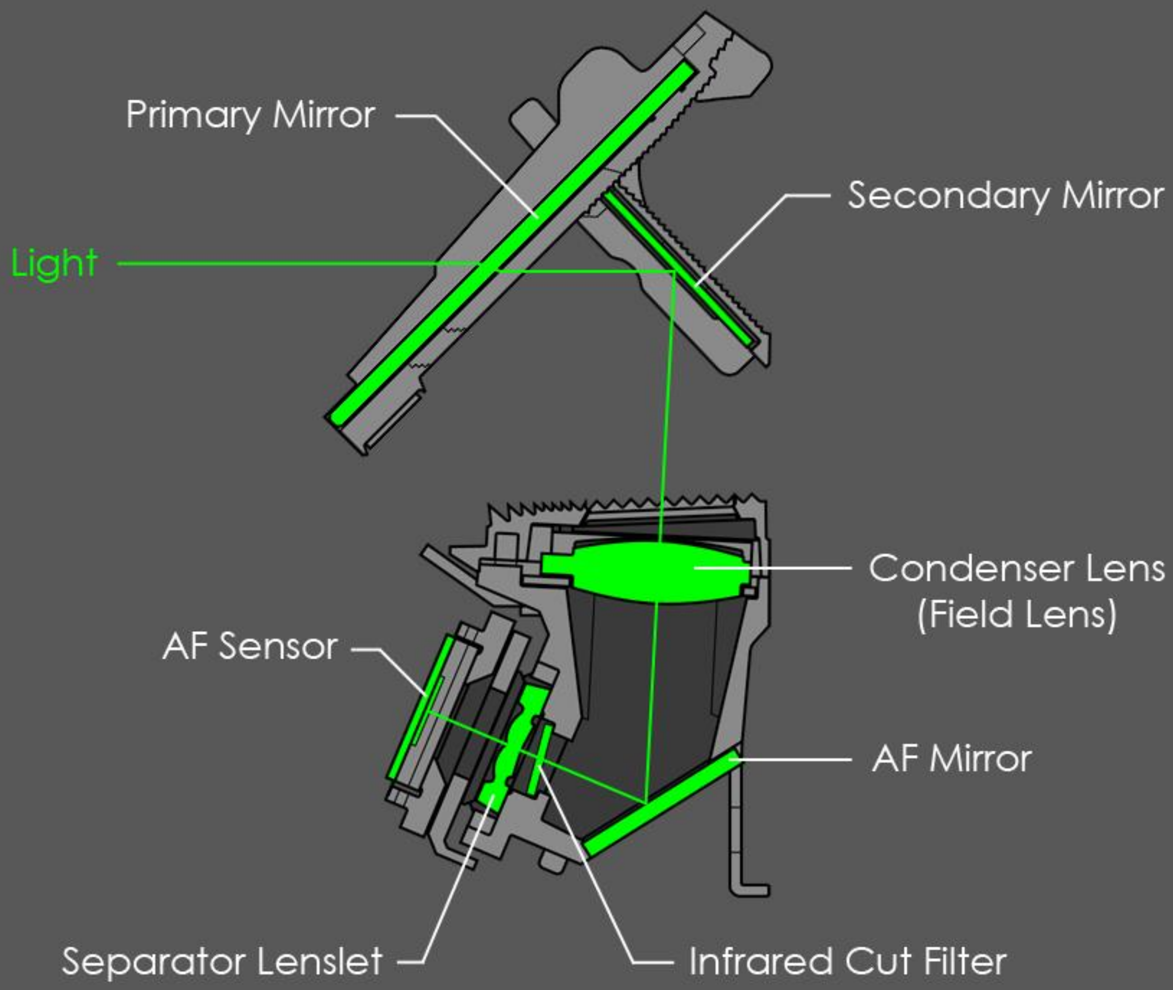
Autofocus Sensor Design - Canon EOS 1DX





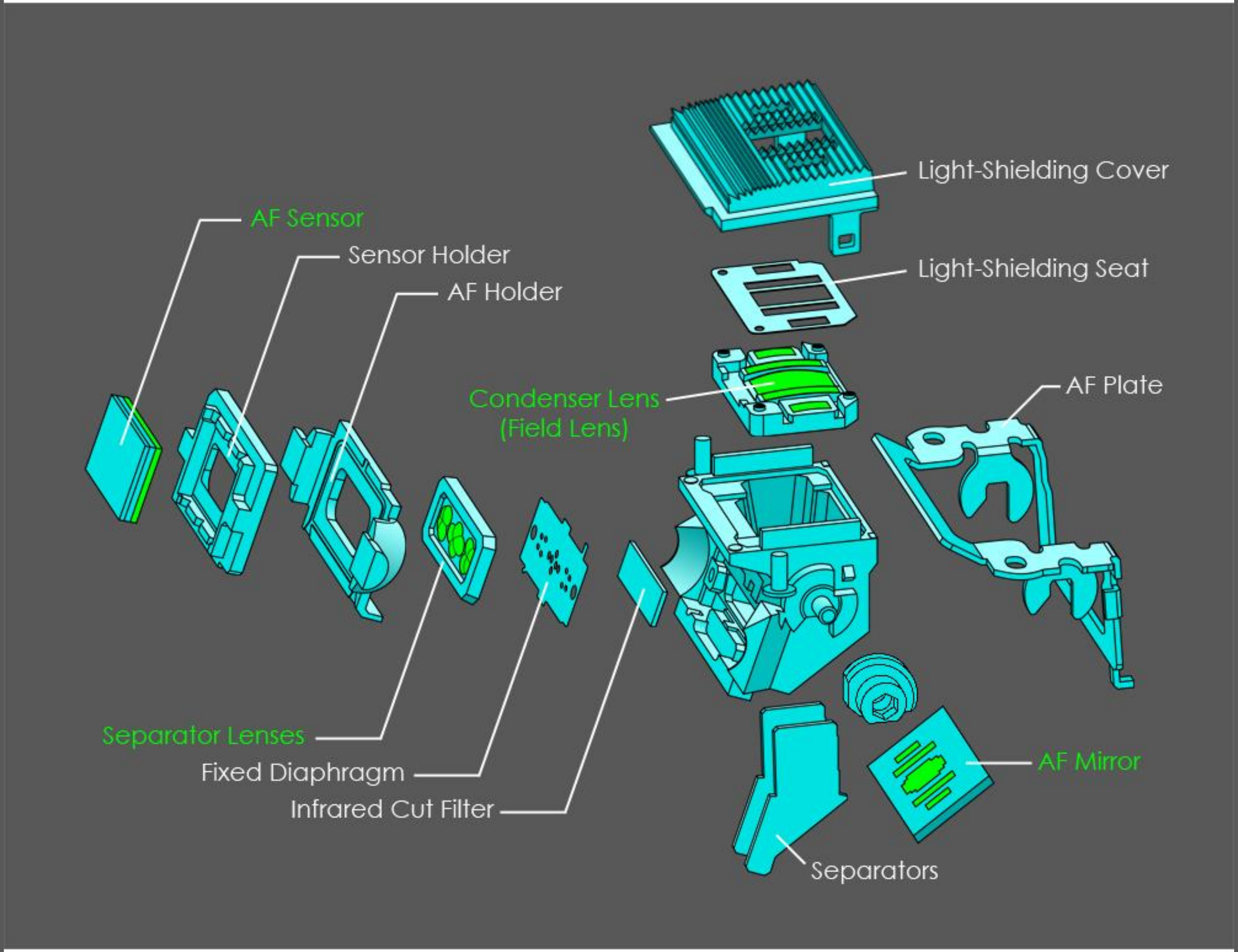
The upper diagram shows the layout of the autofocus sensor of the Canon EOS 1DX with the pairs of CCD strips highlighted in green. The lower diagram illustrates the resulting array of autofocus points.

Phase Detection Sensor Array

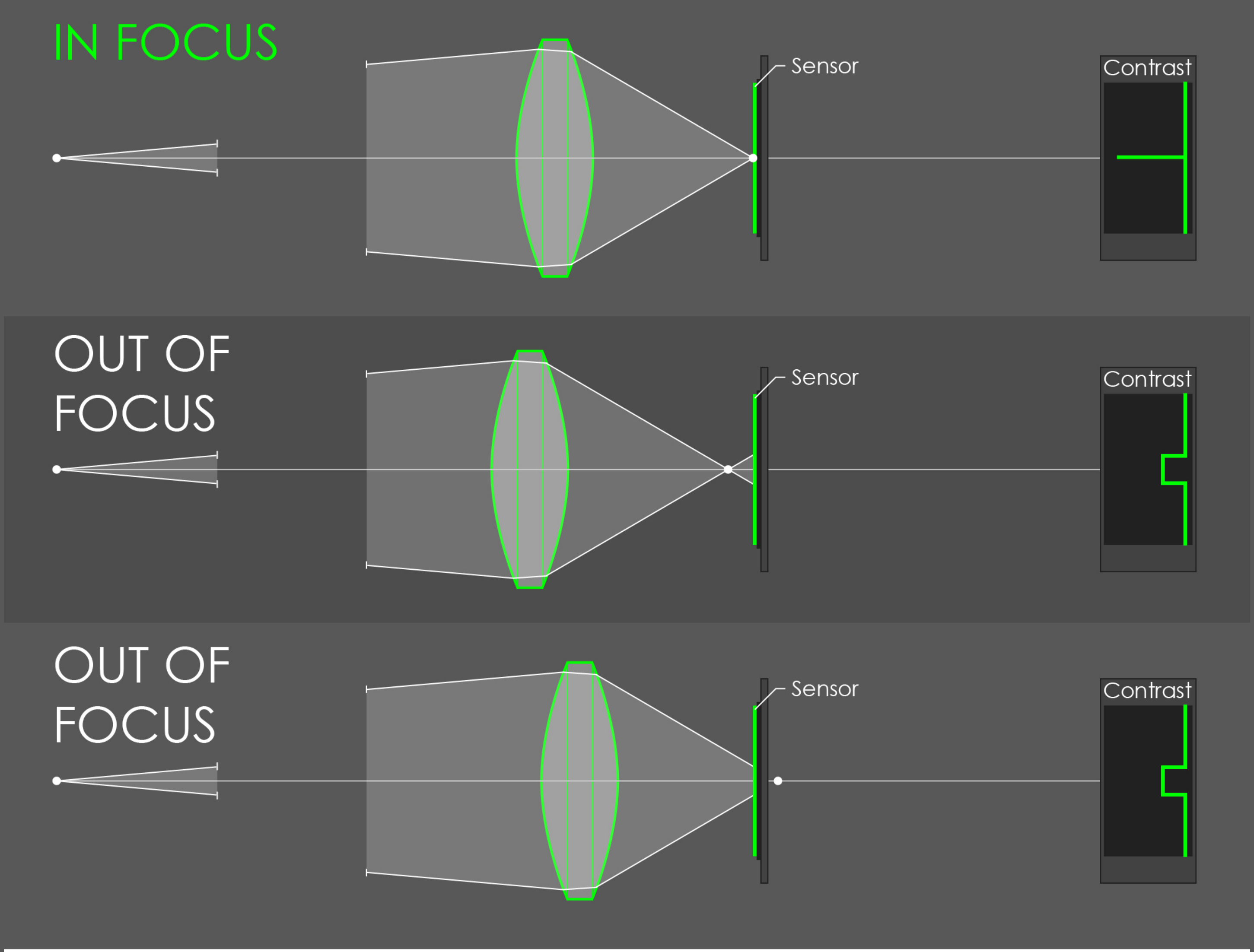


The secondary mirror deflects light from the photographic lens to the phase detection sensor array.

Phase Detection Unit Parts

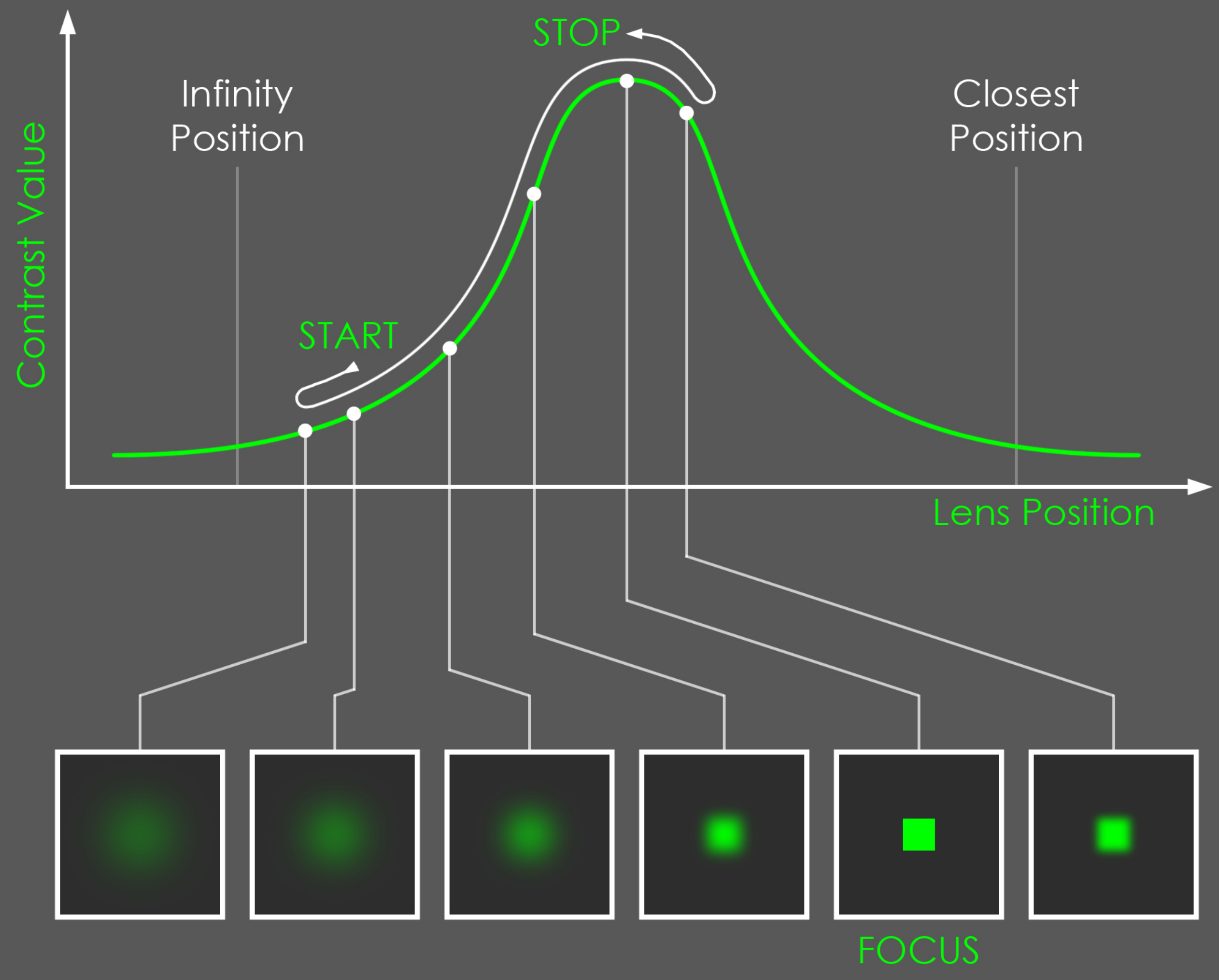


Contrast Detection Autofocus System



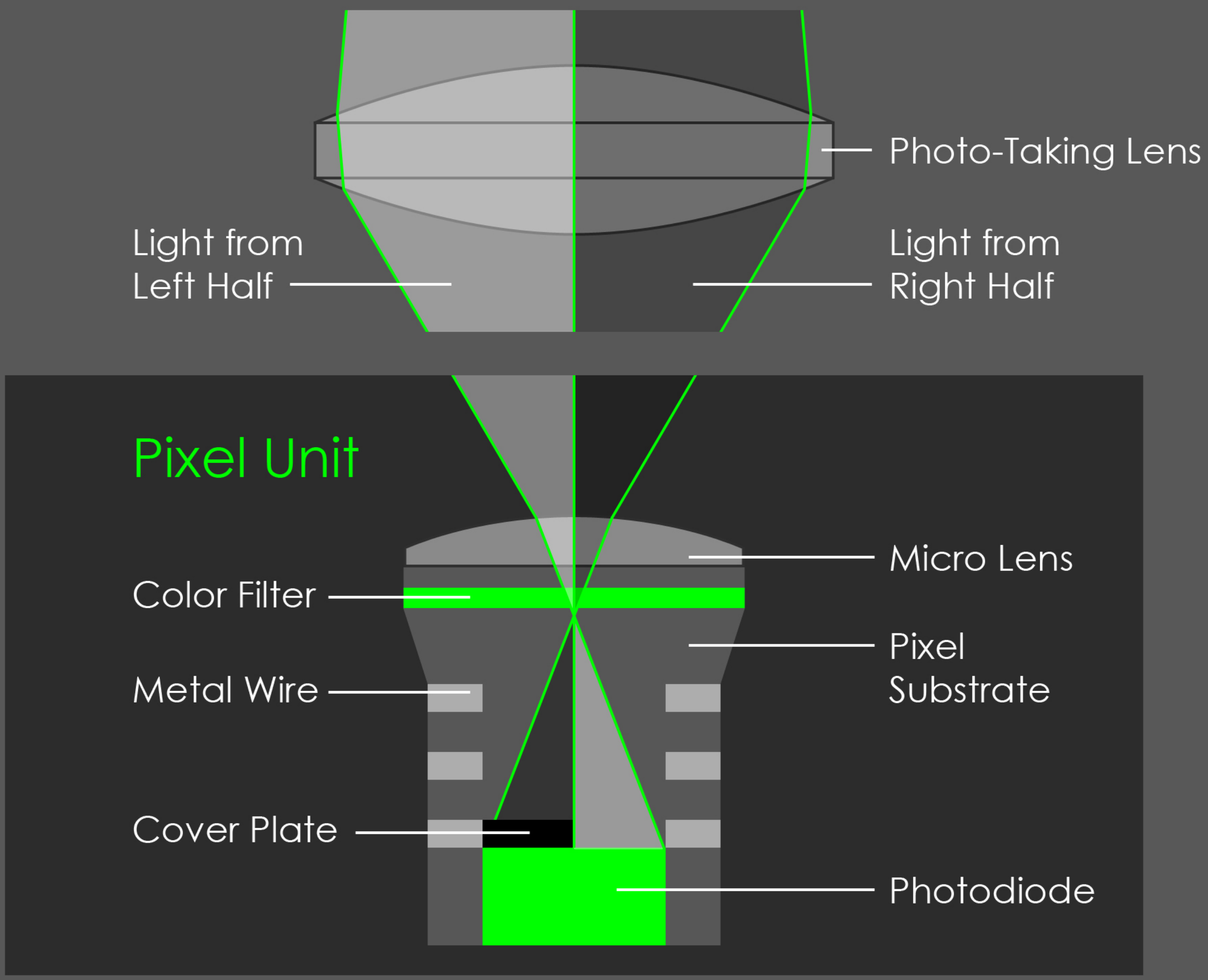
The strongest contrast indicates maximum sharpness in the image.

Contrast Detection - Hill Climbing



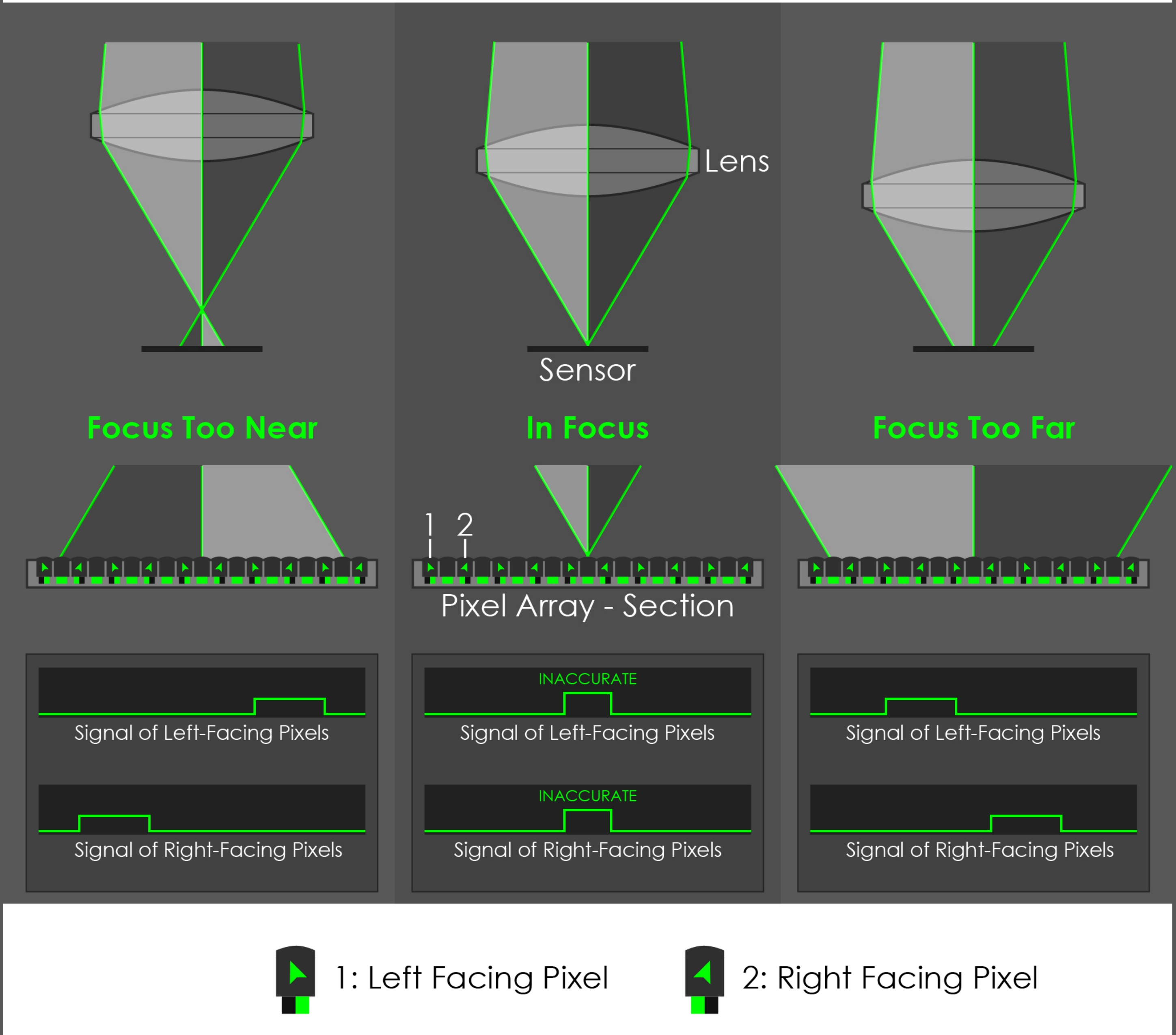
The curve represents the contrast values for a subject at a medium distance from the camera.

Structure of Hybrid CMOS AF Pixel

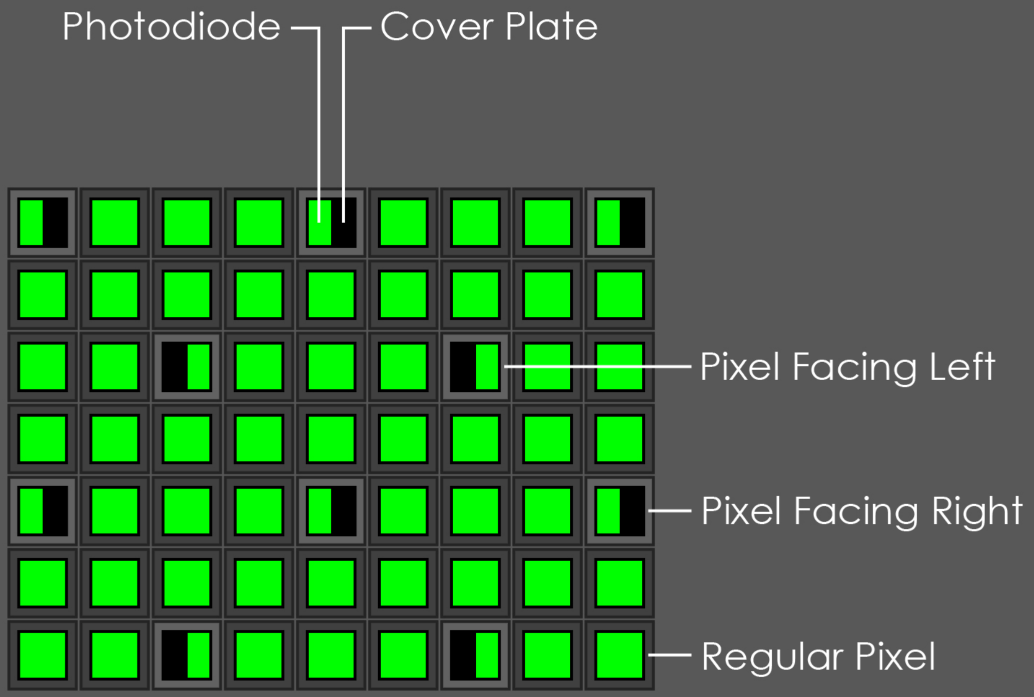


The above pixel unit can only record light coming from the left half of the photo-taking lens.

Hybrid CMOS AF Principle

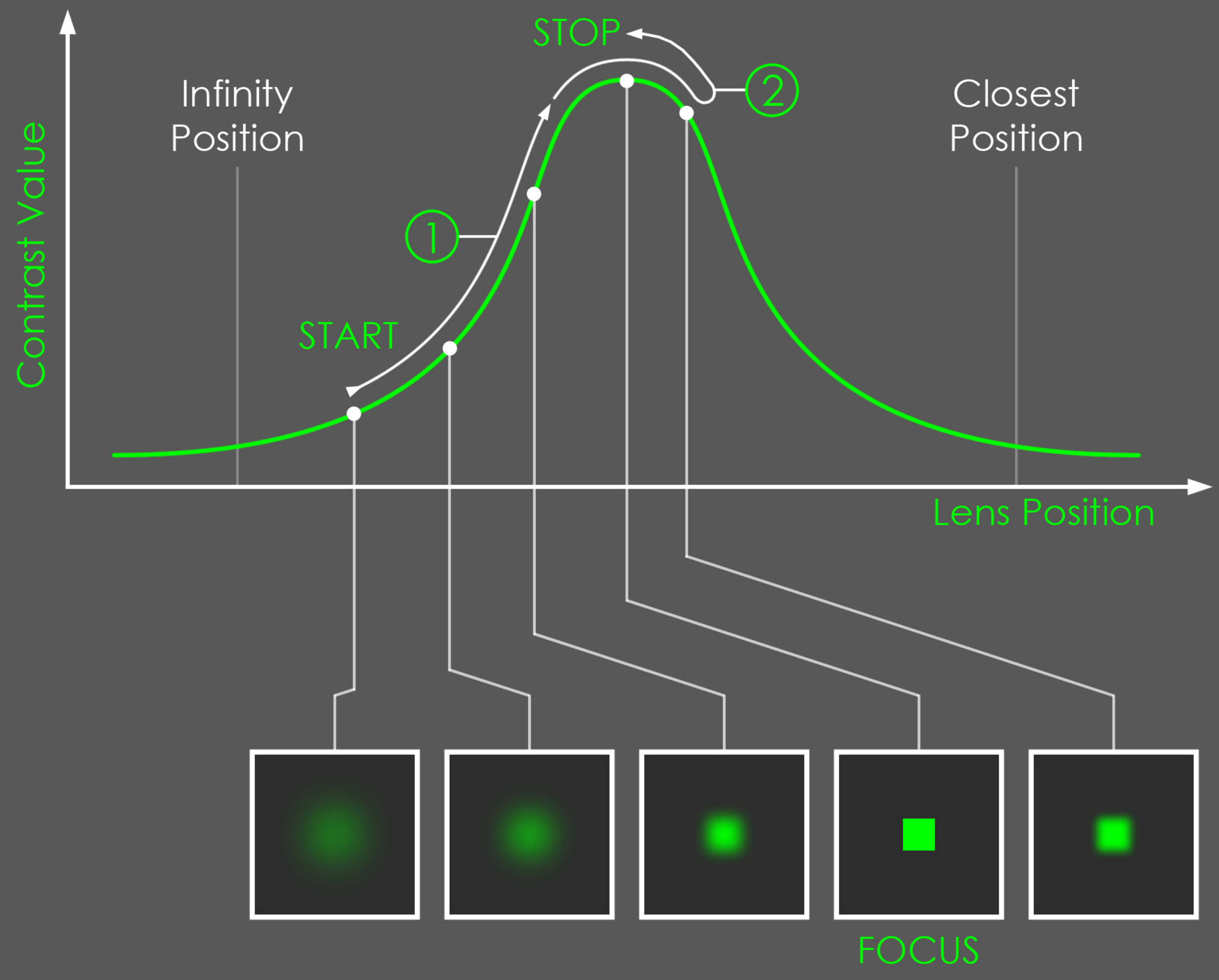


Hybrid CMOS AF - Sensor Layout Top View



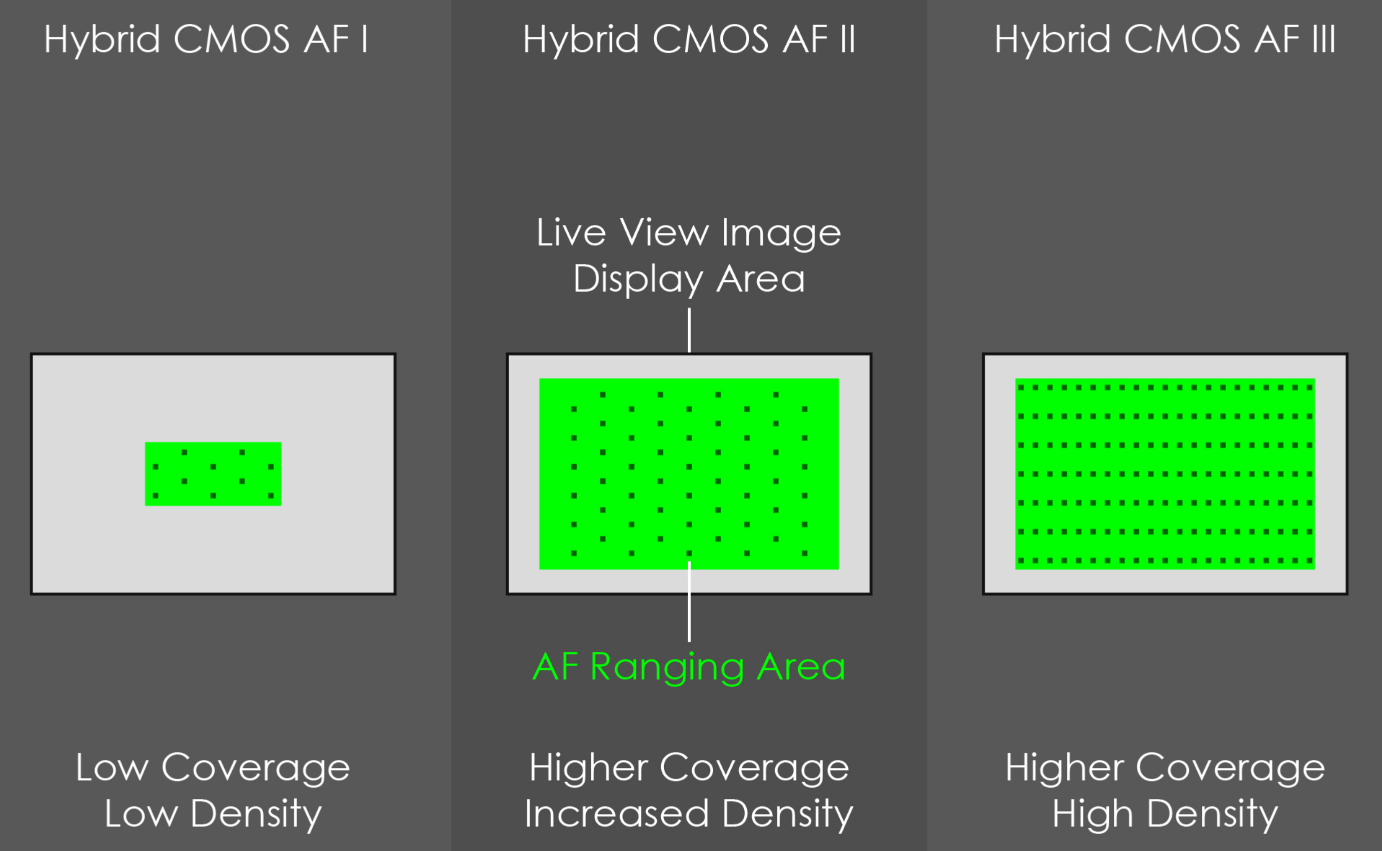
A number of left-oriented pixels and right-oriented pixels are evenly distributed over the image sensor.

Hybrid CMOS AF



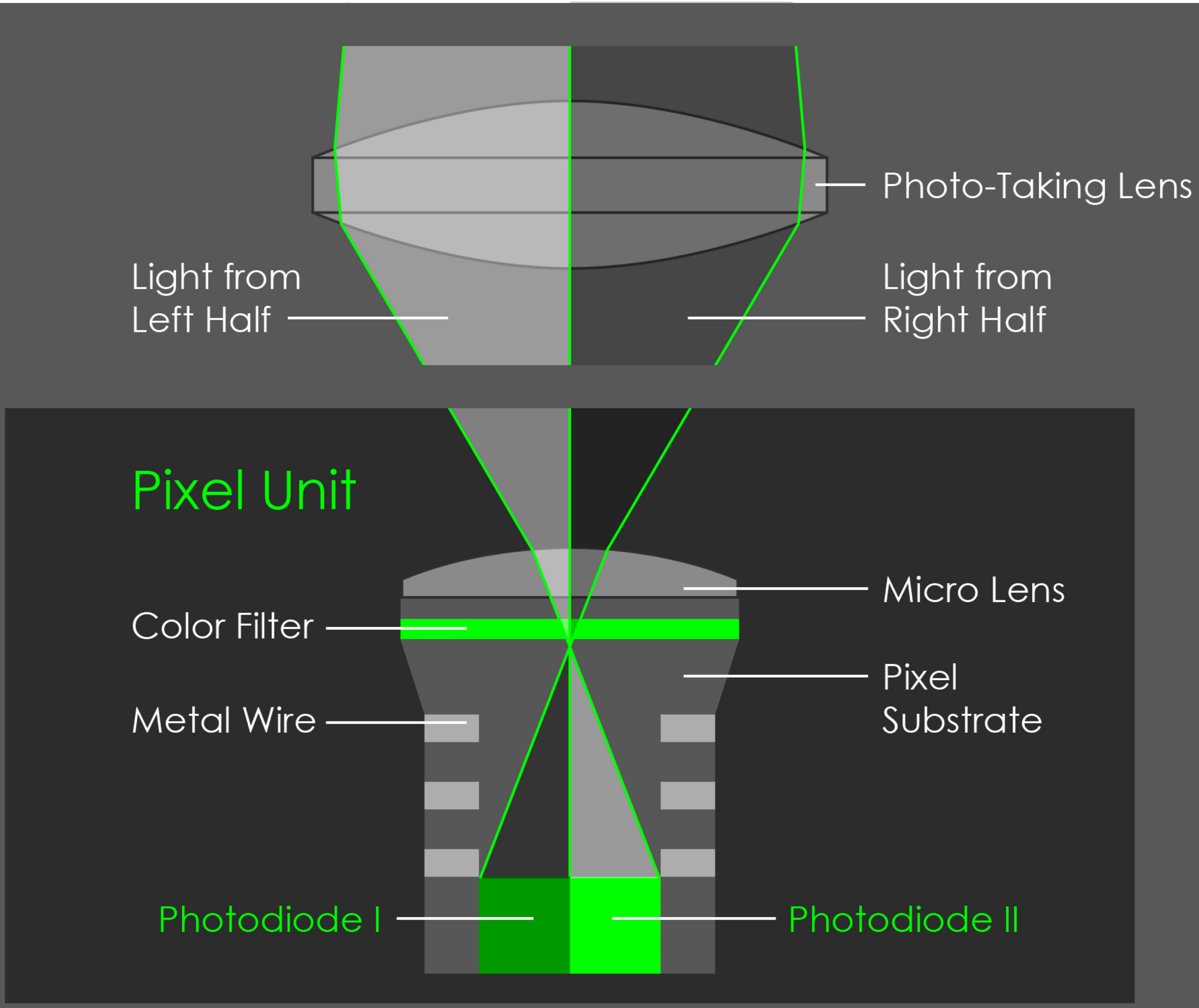
1: Phase Detection
2: Contrast Detection

Hybrid CMOS AF Generations



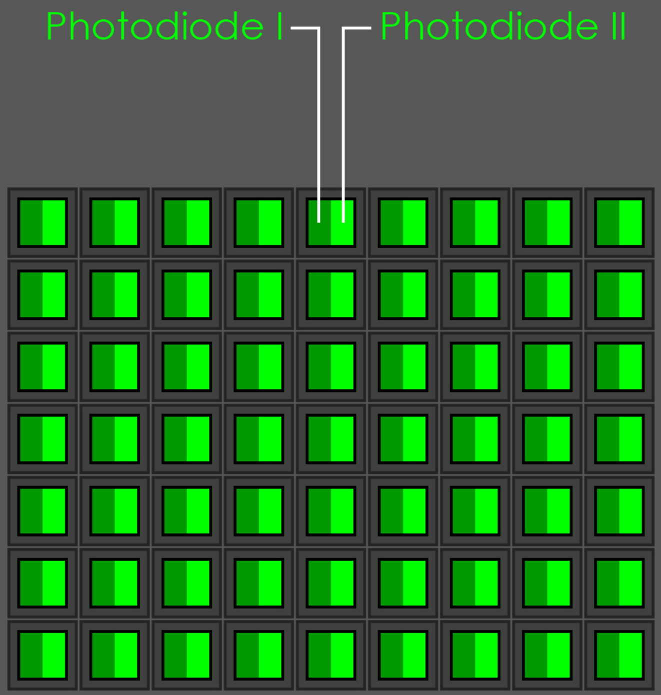
The generations gradually increased both phase-detection pixel coverage and density

Structure of a Dual Pixel CMOS AF Unit



With Dual Pixel CMOS AF technology, each pixel can record light from opposite halves of the photo-taking lens separately.

Dual Pixel CMOS AF - Sensor Layout Top View



With Dual Pixel CMOS AF, all pixels consist of two photodiodes.

Dual Pixel CMOS AF Principle