Eight-Reflections vs. Four-Reflections

**Eight-Reflection Lens:** $f = 38 \text{ mm}$
- $6.7^\circ$ full angle field of view
- Input Aperture
- Planar Mirror
- Omnivision OVT-3610 color CMOS sensor
- Diamond Machined Aspheric Reflectors
- Cross-section

**Four-Reflection Lens:** $f = 19 \text{ mm}$
- $17^\circ$ full angle field of view
- Forza Cu-CMOS 3.0 $\mu$m pixel sensor
- 2 elements: Diamond-machined aspheric reflectors (top and bottom)
- Variable gap (focus)

**Four-Reflection lens:**
- 2 plano-aspheric elements with index-matched gap
- Variable gap focus adjustment
- Pupil phase coding & smaller focal length for increased depth of field

**Result:** 75% smaller, 38% aperture eff., 7x solid angle
Four-Reflection Adjusted Focus Camera

Four-Reflection Lens:
- \( f = 19 \text{ mm}, \ F/\#_{\text{eff}} = 1.15, 17^\circ \text{ FOV} \)
- 1.93 MP Image Sensor (3 \( \mu \text{m} \) pixels)
- 28 mm OD, 5.5 mm thick
- 0.81 obscuration ratio
- Adjustable focus from 3m to infinity
- 11 \( \mu \text{m} \) of lateral color (\( \rightarrow \) remap RGB planes)

Adjustable Squeeze Focus:

Input aperture (38% of surface area)

Adjustment range: 14 \( \mu \text{m} \)
Prototype Optomechanics & Electronics

- Main enclosure body
- Back lens element
- Adjuster ring gear
- Front lens element
- Pinion
- Back lens carrier
- Gel gaps
- Image sensor
- Sensor circuit board
- Back cover

Diamond turned & coated parts

Top (input aperture)

Bottom (sensor)

Ribbon connector high-speed signaling supports full-res video

Connects to USB interface PCB (shown) or multi-camera board

DFC Interactive Camera Environment custom software interface

Eight-Reflection Camera
6.7° field of view, EFL = 38 mm
Exp: 967 ms w/ gain 10
Depth of Field: ~30 mm

Four-Reflection Camera
17° field of view, EFL = 19 mm
Exp: 40 ms w/ gain ~2
Depth of Field: ~120 mm (4x)

4-Reflection vs. 8-Reflection Camera
Summary
- Half Diameter
- 2.5x field of view
- 4x depth of field
- Better sensitivity
- ~Half resolution (due to EFL)

Conventional Comparison:
Sanyo Zoom Lens
F/1.4, EFL = 19 mm
Stray Light in the Four-Reflection Camera

Stray light bench testing by Jason Karp

Focused Signal

- On-axis Stray Light
- Oblique Stray Light

Bright On-axis Source
A central block is needed to prevent on-axis paths through reflector gaps

With a central block
And no bright Oblique sources

Bright Off-axis Source
Clear signal to ±8.5° field,
Glare shield needed for >±9°
Stray Light in the Four-Reflection Camera

Stray light simulations by Jason Karp

Oblique Light suppression: Commercial Tenebraex “Killflash” glare filter

Stray Light

![Graph showing normalized intensity vs. incidence angle with different light suppression methods and FOV.]
Origami Optics Graduates from the Lab

Scenes from UCSD campus w/ the 4fold imager: arc-sectioned aperture w/ killflash glare shield)
Desert Field Test

Yuma Proving Grounds, August 15 2007: 50% relative humidity, ground temperature 127°F

Imager concealed in rock pile, focus fixed, aperture stopped to 35° arc: Active optical volume 0.5 cm³