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Opto Engineering TCEL050 telecentric lens with EL-16-40-TC-VIS-5D integrated

Test report

Zürich, May 2020

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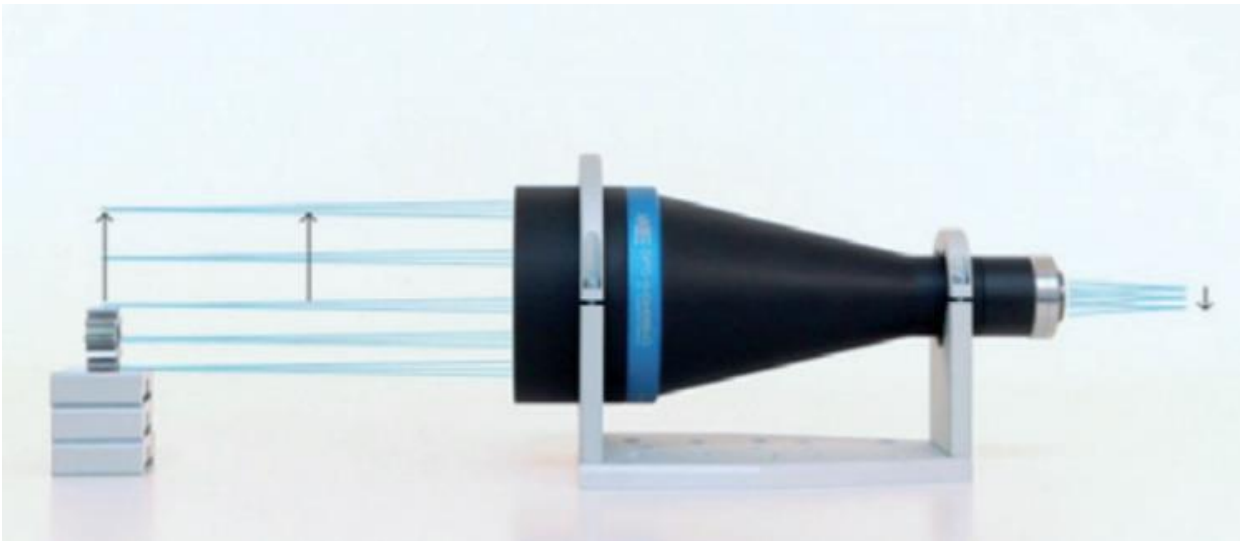
What is a telecentric lens?



TELECENTRIC LENSES only accept incoming ray bundles that are parallel to the optical axis

Images courtesy of Opto Engineering

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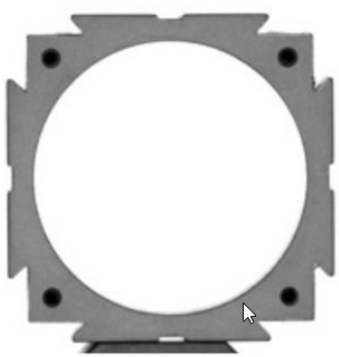
Main benefits of a telecentric lens

Constant magnification

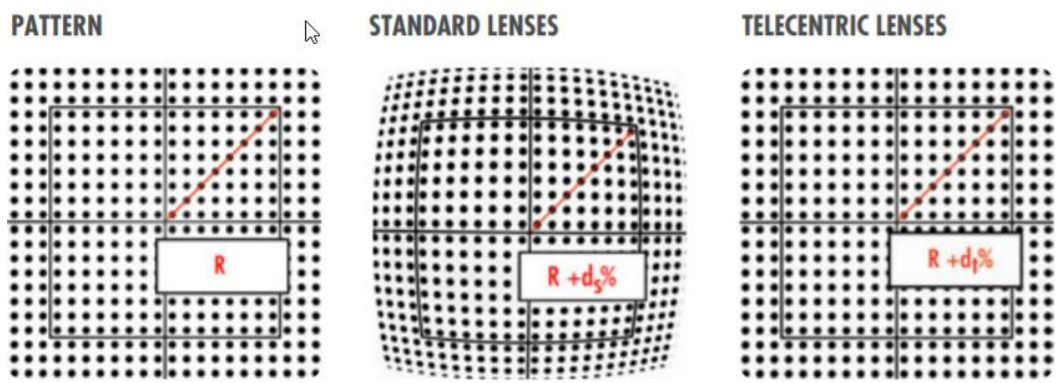
No perspective error

Common optics showing significant image perspective error.



A telecentric lens is able to cancel any perspective effect.

Nearly zero image distortion



Images courtesy of Opto Engineering

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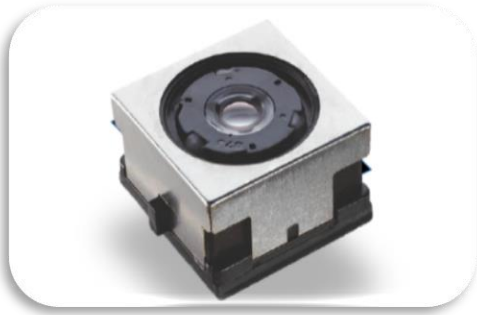
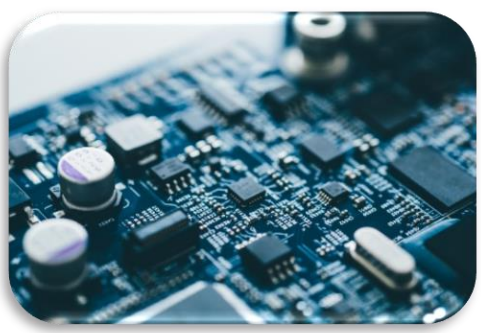
Application examples of telecentric lens + liquid lens

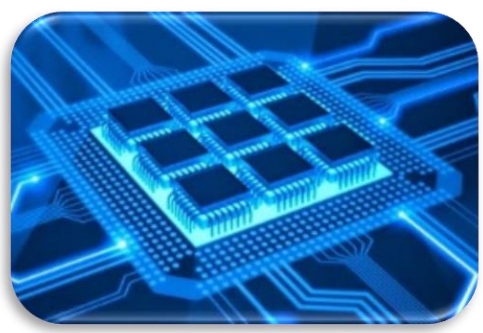
Contact lens inspection



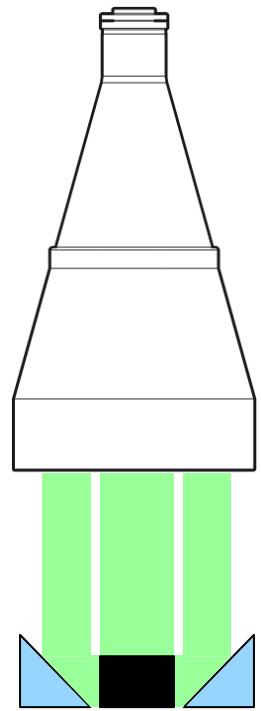
Camera phone lens inspection



Electronics inspection



IC inspection



IC inspection – image 5 sides with one camera

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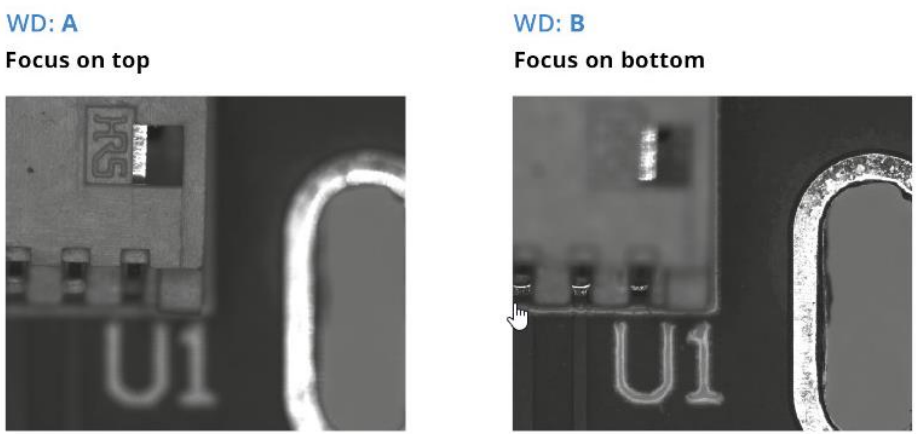
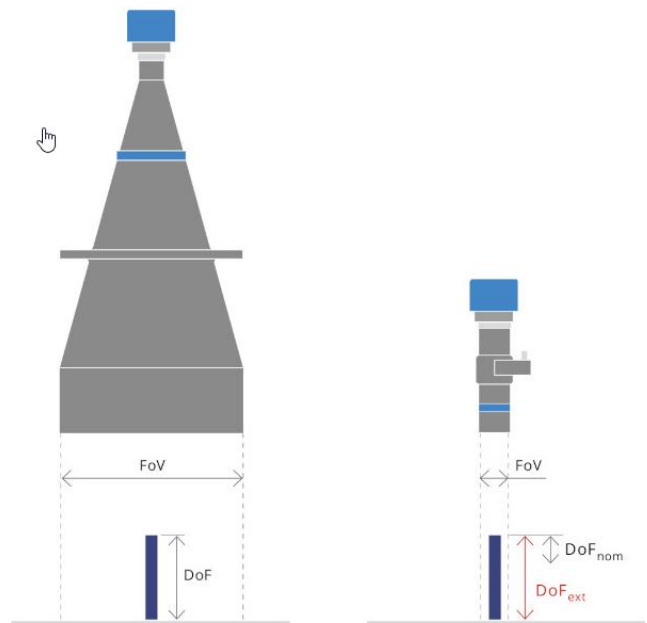
Key takeaways

- The main benefits of a telecentric lens are preserved when using it in conjunction with the Optotune's liquid lens
- TCEL series is particularly suitable for metrology/inspection applications across different planes with high mag. lenses that typically have shallow DoF
- Integrated and cost-effective solution



Focus in various objects with different height.



Images courtesy of Opto Engineering

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Test report summary

- Close to Nyquist limit resolution in all lens orientations
- Very good polychromatic performance
- Large Z-range of 34 mm
  - Optical leverage of 6.8 mm/dpt
- Very small MAG change of 0.11%/mm
- Very low distortion <0.1%

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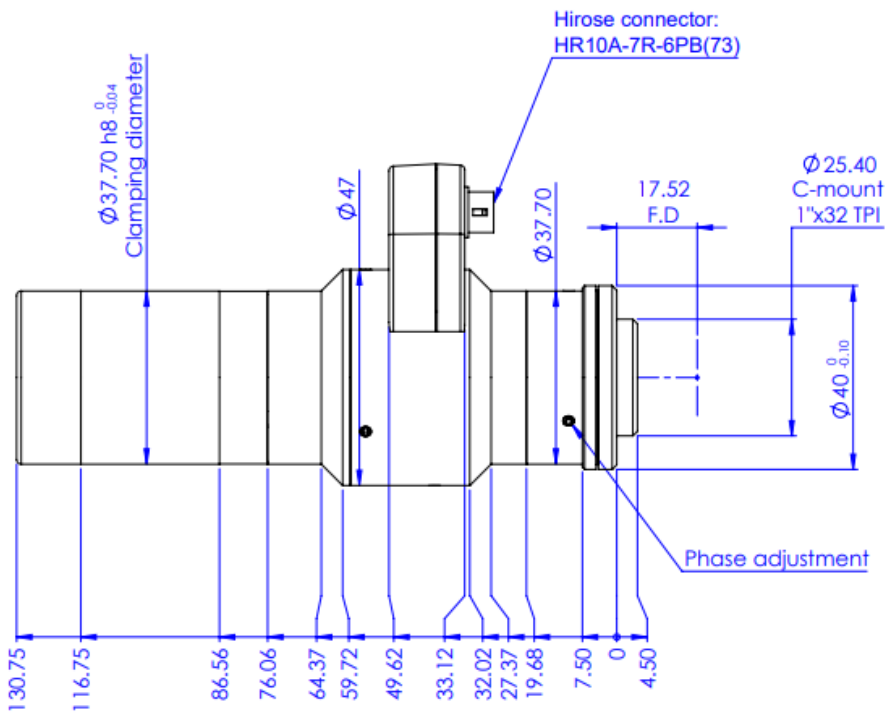
Datasheet

Specifications

Nominal magnification at 0 dpt	(x)	0.500
Magnification ranges at -2 dpt to +3 dpt	(x)	0.491 - 0.508
Max sensor size	(mm)	2/3"

Object field of view (1)		
with 1/3" detector (4.8 x 3.6 mm)	(mm)	9.6 x 7.2
with 1/1.8" detector (7.13 x 5.33 mm)	(mm x mm)	14.3 x 10.7
with 2/3" - 5 MP detector (8.50 x 7.09 mm)	(mm x mm)	17.0 x 14.2

Optical specifications		
Working distance **(2)**	(mm)	132.3
Working distance range at -2 dpt to +3 dpt **(3)**	(mm)	112.2 - 146.5
wF/# **(4)**		12
Telecentricity **(5)**	(deg)	< 0.04 (0.08)
Telecentricity typical (max) **(6)**	(deg)	< 0.15
Distortion **(7)**	(%)	< 0.1 (0.2)
Distortion typical (max) **(6)**	(%)	< 0.2
Field depth **(8)**	(mm)	2.5
CTF@ 35 lp/mm	(%)	> 60



https://www.opto-e.com/products/TCEL050

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Test setup

Camera:	2/3" (IDS UI-3200-M-GL) 2456x2054 pixels, 3.45 um px
Lens:	Opto Engineering TCEL050 with EL-16-40-TC-VIS-5D integrated
F/#	12 (fixed)
Driver:	Optotune Lens Driver 4
Target:	Transparent USAF target
Light:	White backlight
Optical axis:	Vertical

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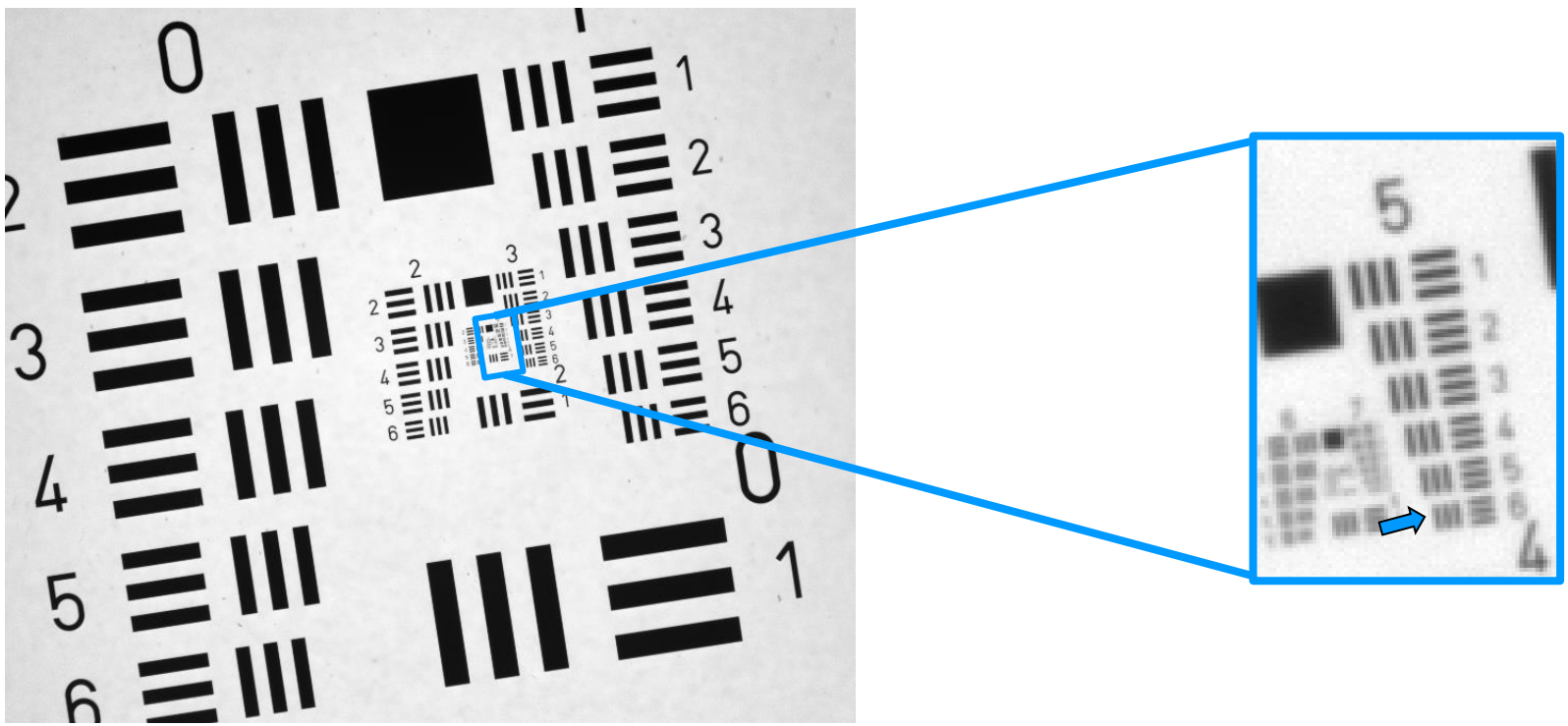
Method for image evaluation

- After acquisition, images are zoomed in to show resolution limited element



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WD = 132 @ 0dpt, PMAG=0.5, white backlight

Camera

Sensor size = 2456x2054 pixels

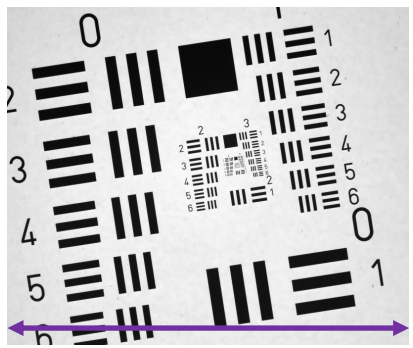
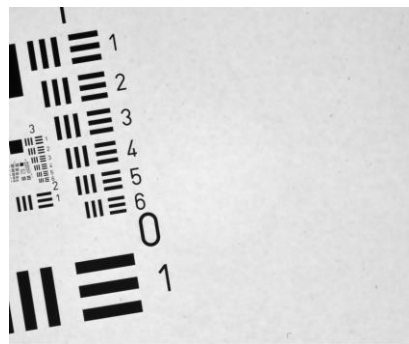
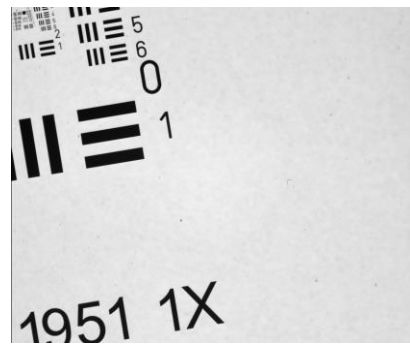
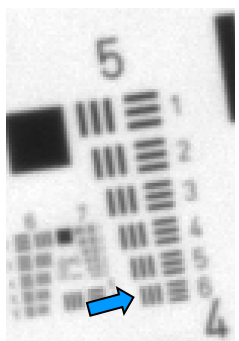
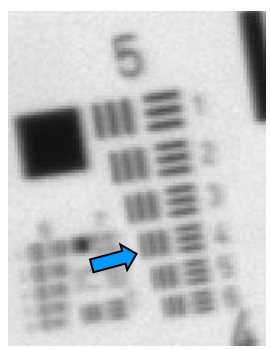
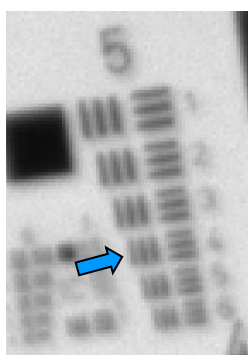
Nyquist limit = 144 lp/mm

Pixel size = 3.45 um

Exposure time = 30 ms

Light

White background illumination

	Center	Edge	Corner
			
	16.9 mm		
			
USAF element:	5/6	5/4	5/4
Line width (um):	8.77	11.05	11.05
Lp/mm (object):	57	45	45
Magnification:	0.499	0.499	0.499
Lp/mm (image):	**114**	**91**	**91**

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WD = 112 @ 3dpt, PMAG=0.508, white backlight

Camera

Sensor size = 2456x2054 pixels

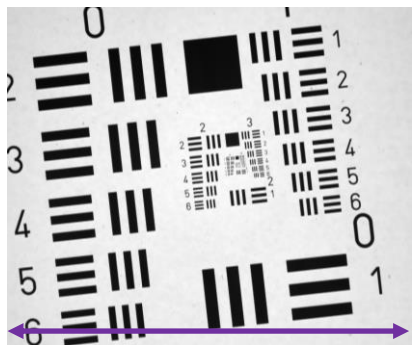
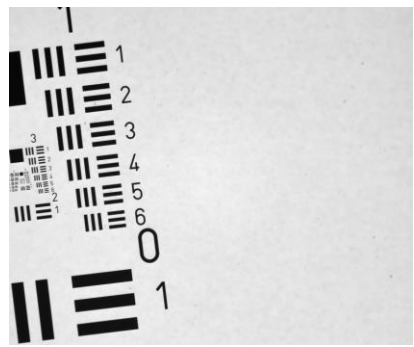
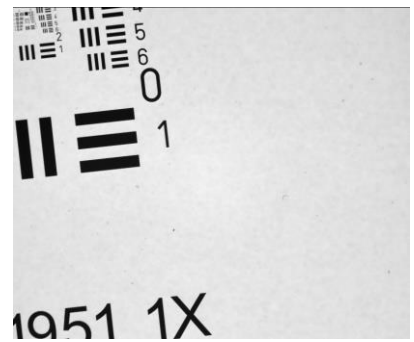
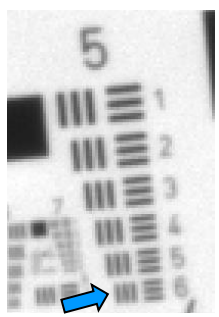
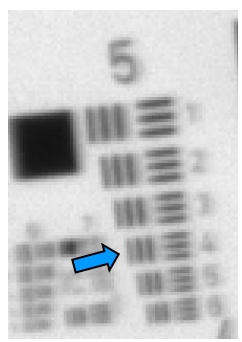
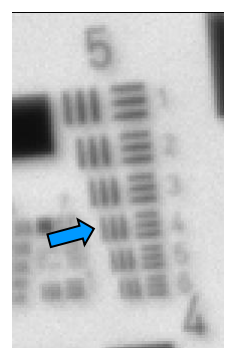
Nyquist limit = 144 lp/mm

Pixel size = 3.45 um

Exposure time = 30 ms

Light

White background illumination

	Center	Edge	Corner
			
	16.7 mm		
			
USAF element:	5/6	5/4	5/4
Line width (um):	8.77	11.05	11.05
Lp/mm (object):	57	45	45
Magnification:	0.508	0.508	0.508
Lp/mm (image):	**112**	**89**	**89**

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WD = 146 @ -2dpt, PMAG=0.493, white backlight

Camera

Sensor size = 2456x2054 pixels

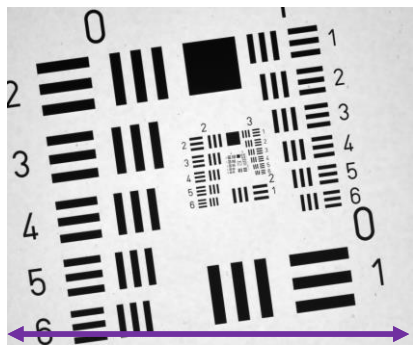
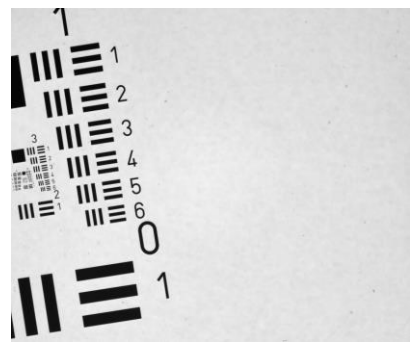
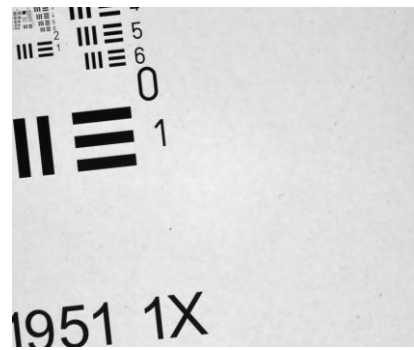
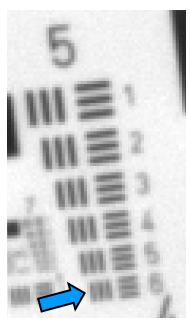
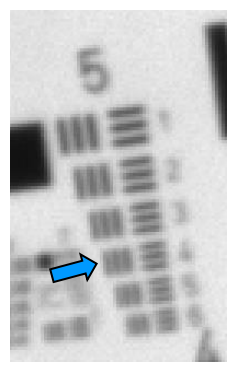
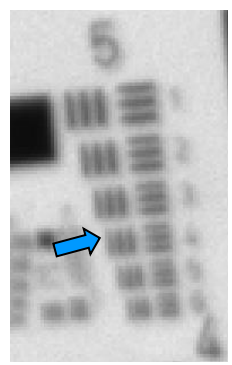
Nyquist limit = 144 lp/mm

Pixel size = 3.45 um

Exposure time = 30 ms

Light

White background illumination

	Center	Edge	Corner
			
	17.2 mm		
			
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Lp/mm (object):	57	45	45
Magnification:	0.493	0.493	0.493
Lp/mm (image):	**116**	**92**	**92**

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Test setup with red backlight

Camera:	2/3" (IDS UI-3200-M-GL) 2456x2054 pixels, 3.45 um px
Lens:	Opto Engineering TCEL050 with EL-16-40-TC-VIS-5D integrated
F/#	12 (fixed)
Driver:	Optotune Lens Driver 4
Target:	Transparent USAF target
Light:	Red backlight
Optical axis:	Vertical

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WD = 132 @ 0dpt, PMAG=0.5

Camera

Sensor size = 2456x2054 pixels

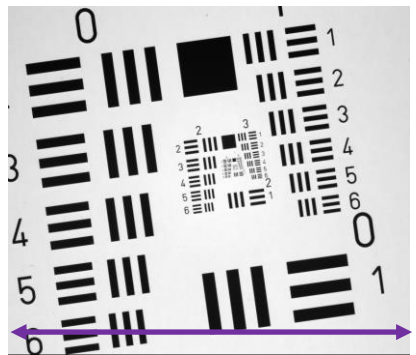
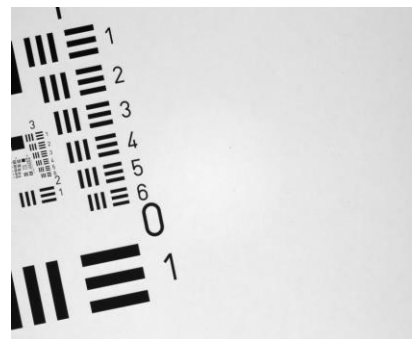
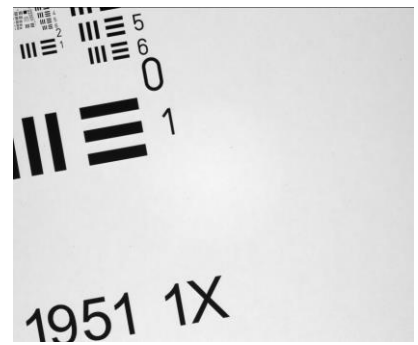
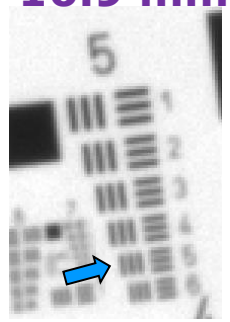
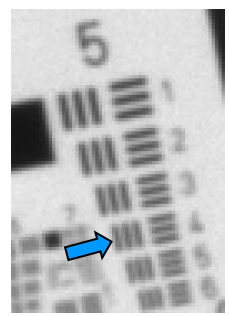
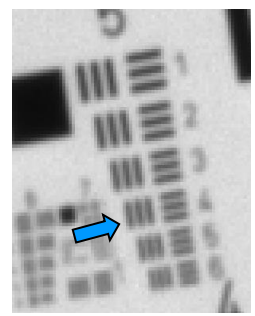
Nyquist limit = 144 lp/mm

Pixel size = 3.45 um

Exposure time = 20 ms

Light

Red background illumination

	Center	Edge	Corner
			
			
USAF element:	5/5	5/5	5/5
Line width (um):	9.84	9.84	9.84
Lp/mm (object):	51	51	51
Magnification:	0.499	0.499	0.499
Lp/mm (image):	**102**	**102**	**102**

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WD = 112 @ 3dpt, PMAG=0.508

Camera

Sensor size = 2456x2054 pixels

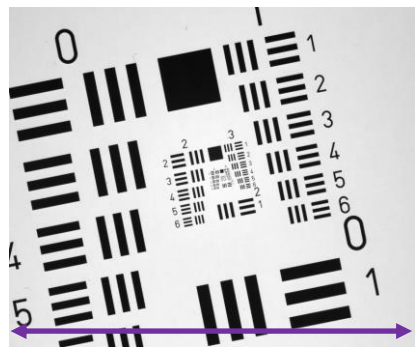
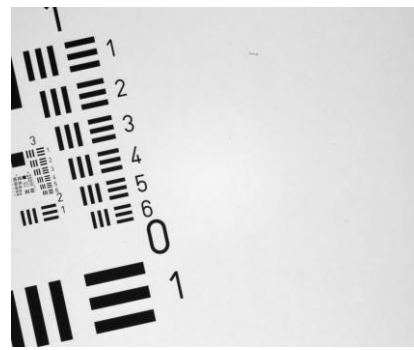
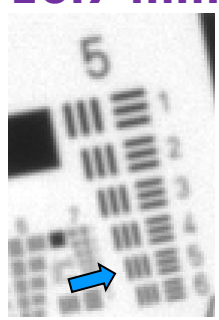
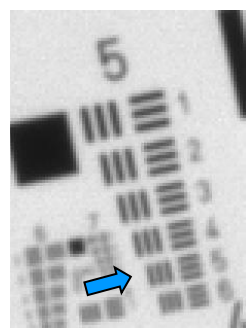
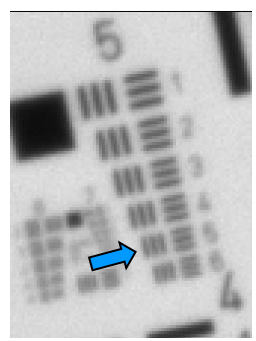
Nyquist limit = 144 lp/mm

Pixel size = 3.45 um

Exposure time = 20 ms

Light

Red background illumination

	Center	Edge	Corner
			
	16.7 mm		
			
USAF element:	5/5	5/5	5/5
Line width (um):	9.84	9.84	9.84
Lp/mm (object):	51	51	51
Magnification:	0.508	0.508	0.508
Lp/mm (image):	**100**	**100**	**100**

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WD = 146 @ -2dpt, PMAG=0.493

Camera

Sensor size = 2456x2054 pixels

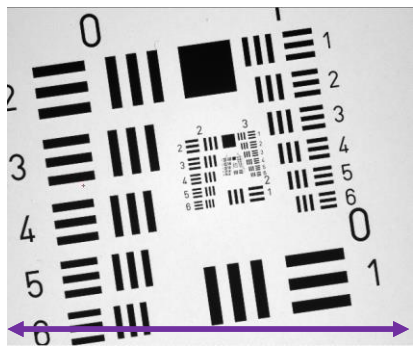
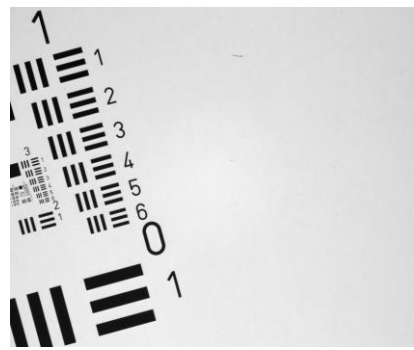
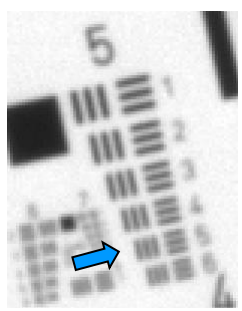
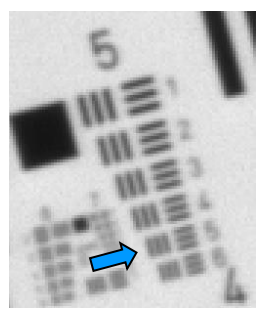
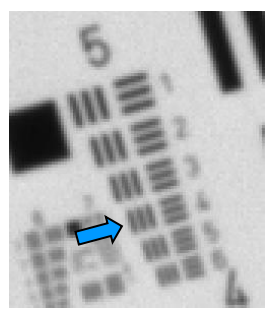
Nyquist limit = 144 lp/mm

Pixel size = 3.45 um

Exposure time = 20 ms

Light

Red background illumination

	Center	Edge	Corner
			
	17.2 mm		
			
USAF element:	5/6	5/5	5/4
Line width (um):	8.77	9.84	11.05
Lp/mm (object):	57	51	45
Magnification:	0.493	0.493	0.493
Lp/mm (image):	**116**	**103**	**92**

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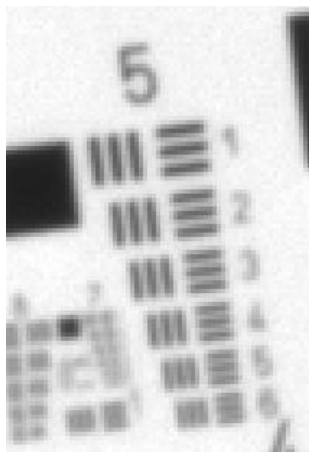
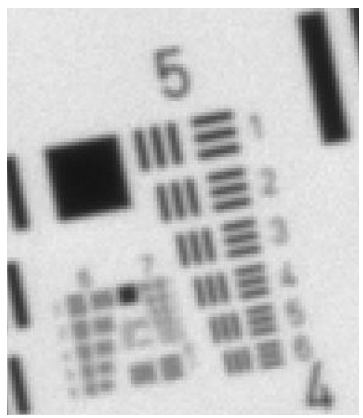
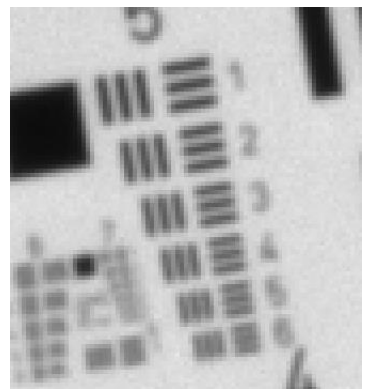
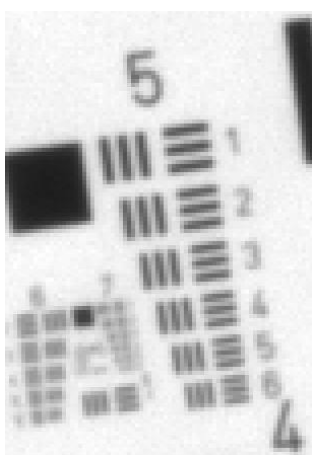
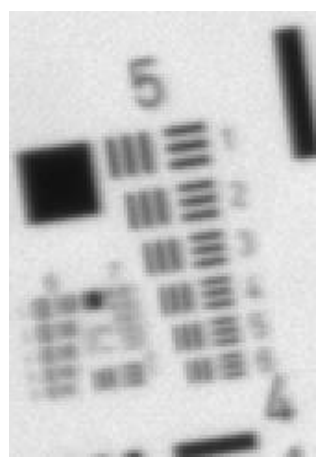
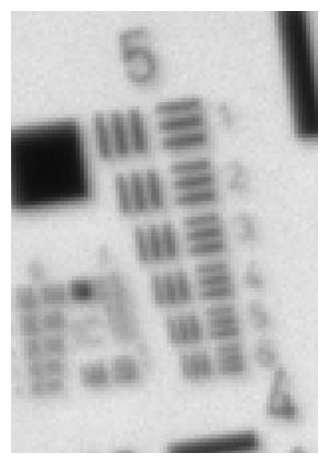
WD = 132 @ 0dpt, PMAG=0.5, white vs. red backlight

	Center	Edge	Corner
Red			
White			

Better image quality in the center with white light but also more degradation on corners and edges

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WD = 132 @ 0dpt, PMAG=0.5, white backlight, horizontal optical axis

Camera

Sensor size = 2456x2054 pixels

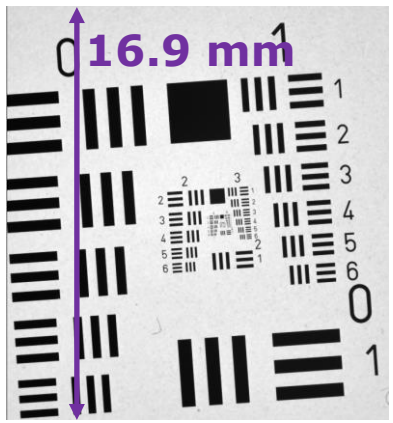
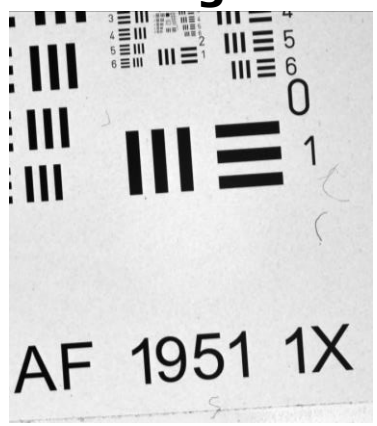
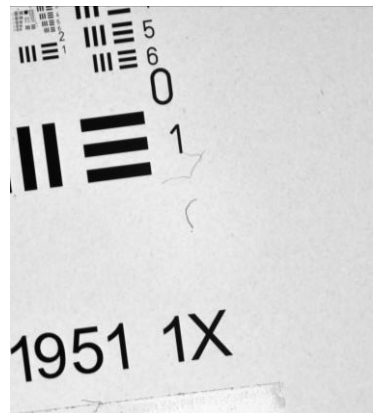
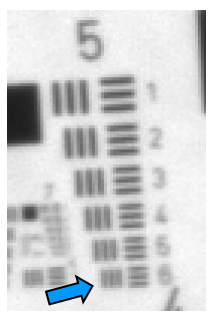
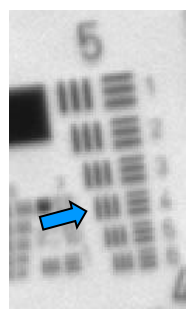
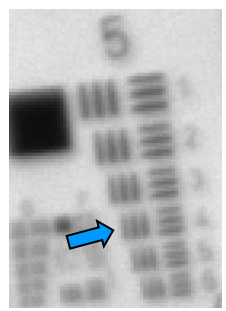
Nyquist limit = 144 lp/mm

Pixel size = 3.45 um

Exposure time = 30 ms

Light

White background illumination

	Center	Edge	Corner
			
			
USAF element:	5/6	5/4	5/4
Line width (um):	8.77	11.05	11.05
Lp/mm (object):	57	45	45
Magnification:	0.499	0.499	0.499
Lp/mm (image):	**114**	**91**	**91**

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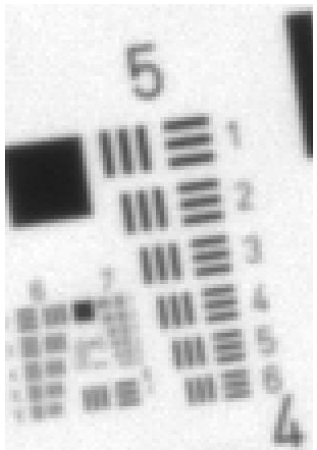
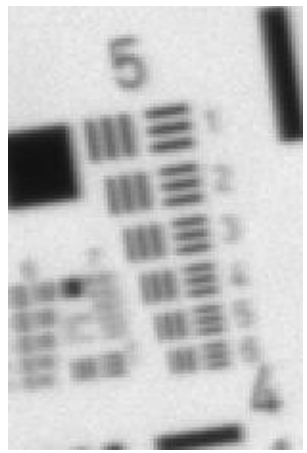
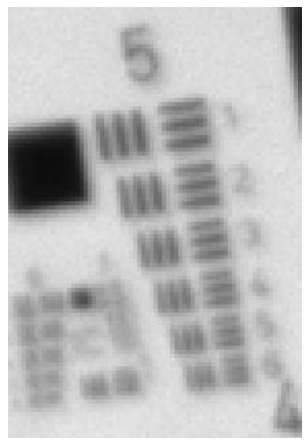
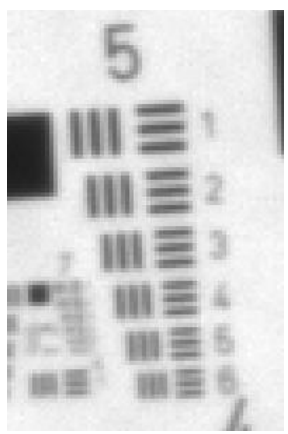
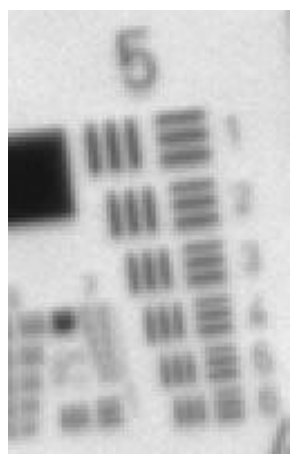
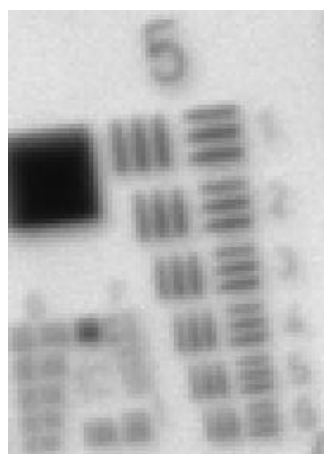
WD = 132 @ 0dpt, PMAG=0.5, white backlight, horizontal optical axis

	Center	Edge	Corner
Vertical			
Horizontal			

Hardly any difference in horizontal vs vertical optical axis

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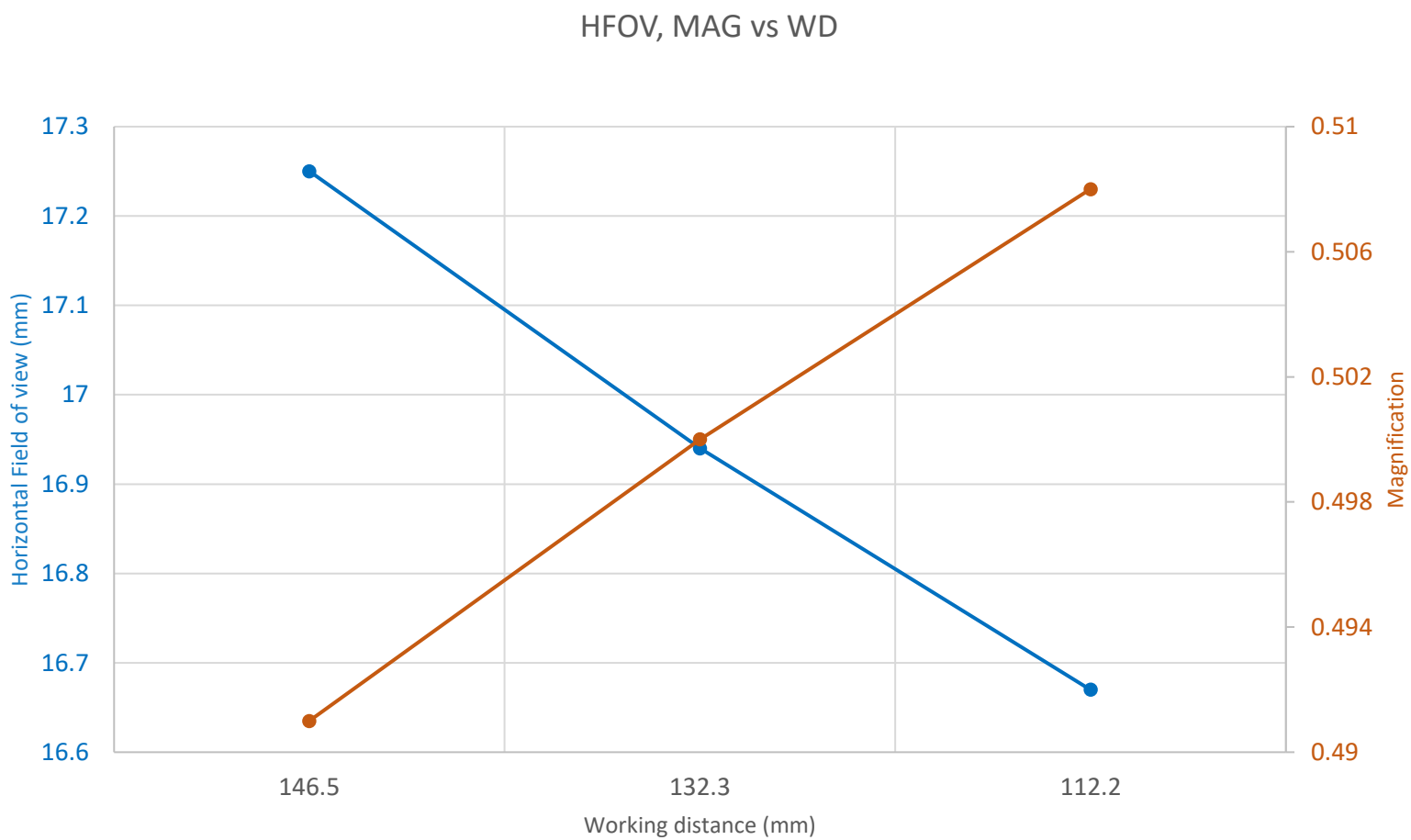
Magnification change: 0.11% per mm of WD



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