



shaping the future of optics



Optotune ELM-0.60-8.0-18-160 (Linkhou TS11-06-160-EL)

Test report

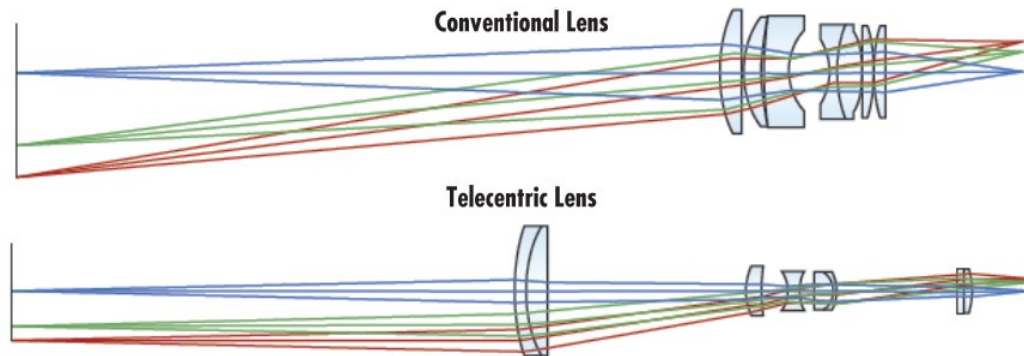
September 2023
Amir Saba, Application Engineer

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Introduction to telecentric lenses

Telecentric lenses only accept incoming ray bundles that are parallel to the optical axis.

- Their entrance and/or exit pupils are at infinity
- The tunable telecentricity can be achieved by putting the Optotune liquid lens near the aperture stop

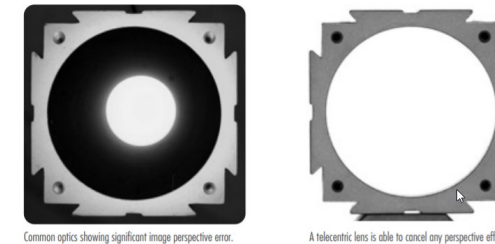


Main benefits:

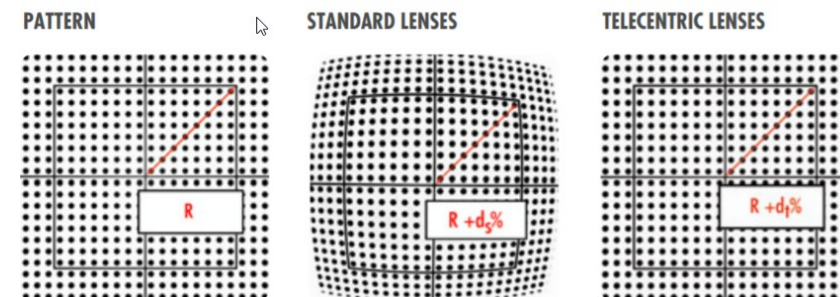
- Constant magnification



- No perspective error



- Nearly zero image distortion

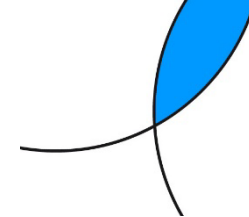


Summary

- **Up to 40mm working distance range**
- **High resolution of up to 6 μ m on the object**
 - Very similar performance with and without the liquid lens
 - Performance close to the Nyquist rate for the recommended pixel size of 3.45 μ m
- **Low magnification change of only 0.17%/mm**
- **Very negligible field curvature and distortion**
 - Magnification and resolutions stays constant across the field
- **MTF of 55% @80Lp/mm (~50lp/mm in object)**
 - Only 2% of MTF drop by adding and tuning the liquid lens
- **Very good polychromatic performance**
 - Performance very similar between white and red backlights



TS11-06-160-EL Datasheet



Lens module specifications

Focus tunable lens (Optotune)	Model	EL-16-40-TC-VIS-5D			
	Focal power	-2	0	+3	dpt
Magnification		0.585	0.598	0.616	X
F/#		8.0			(Fixed)
Maximum sensor format		1.1			inch
Image circle (Φ)		18.4			mm
FoV (at max sensor format) H x V		24.1×17.6	23.5×17.2	22.9×16.7	mm
Working distance		176	160	136	mm
Field depth		0.9			mm
Optical leverage		8			mm/dpt
Optical Distortion		≤0.1	≤0.1	≤0.1	%
Telecentricity		≤0.1	≤0.1	≤0.1	°
Pixel size recommended		3.45			μm
MTF @ 50 lp/mm		58			%
Wavelength range		400-700			nm
Lifecycles (10-90% sinusoidal)		>1'000'000'000			cycles
Mount		C			
Dimension (Φ x L)		Φ53×182.8			mm
Weight		404			g

Focus tunable lens specifications

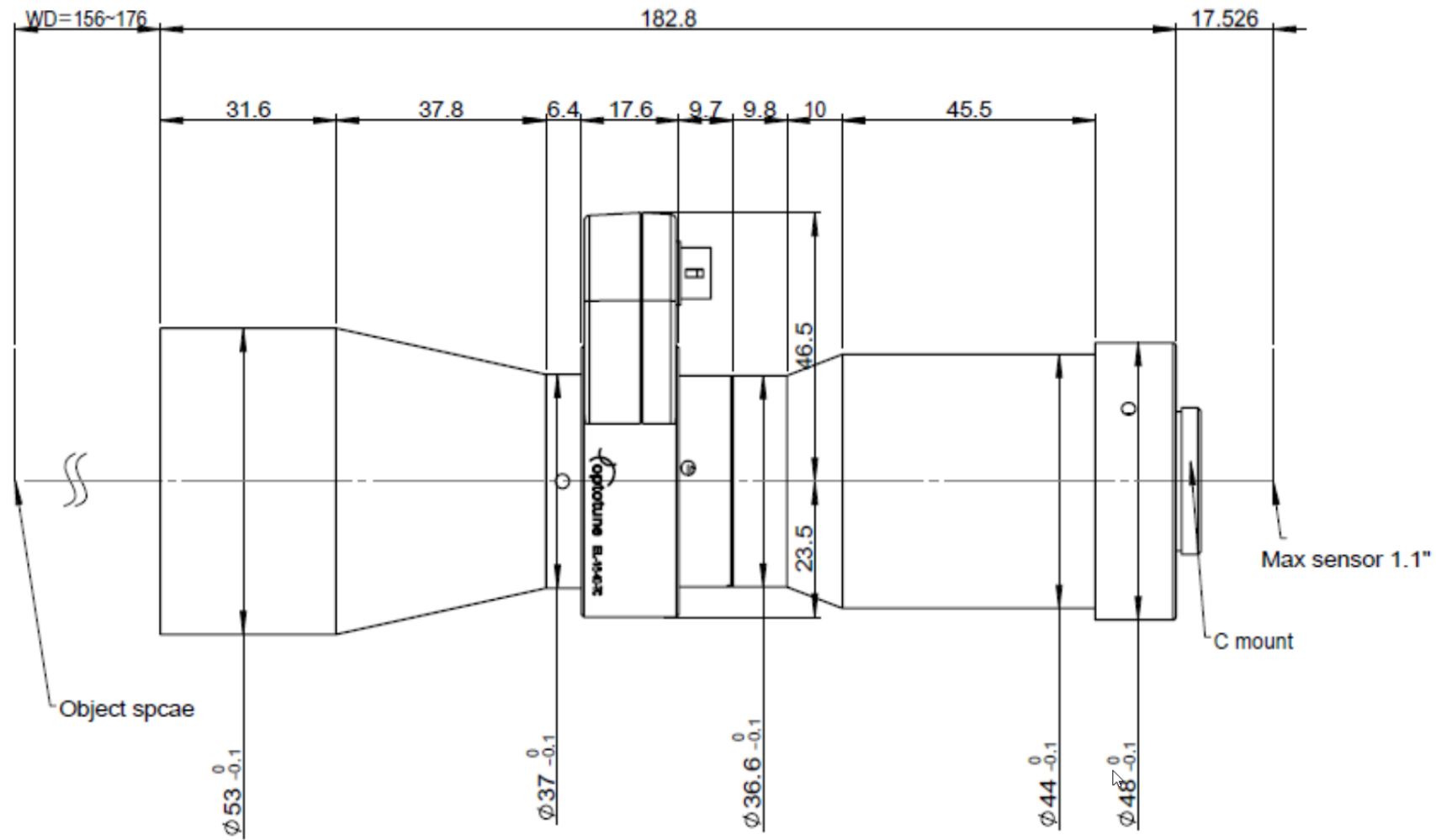
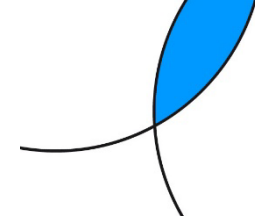
EL-16-40-TC-VIS-5D

Focal power range (@30°C) ³	-2 to +3	dpt
Wavefront error (at 525 nm & 0 mA) Optical axis vertical / horizontal	<0.25/<0.5	λRMS
Operating temperature	-20 to +65	°C
Storage temperature	-40 to +85	°C
Temperature sensor & memory	STTS2004	(STMicroelectronics)

Electrical specifications

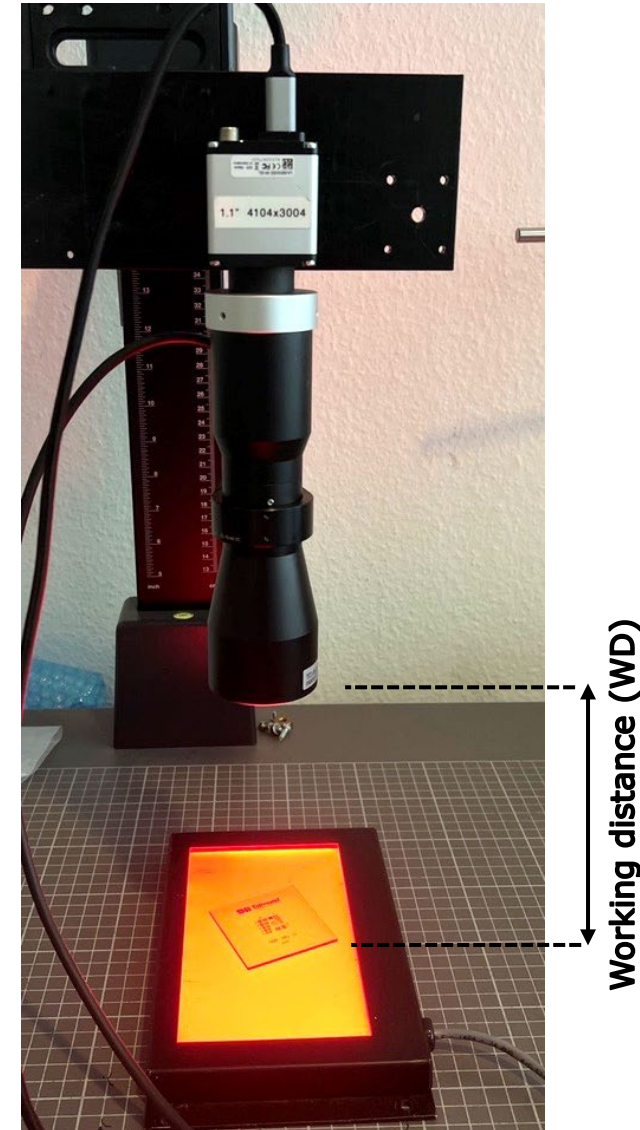
Control current (typical)	-250 to +250	mA
Absolute max. control current	-500 to 500	mA
Power consumption	0 to 0.7 (nominal) 0 to 2.8 (absolute max.)	W
Motor coil resistance @ 30°C	12	Ω
Absolute maximum voltage (coil)	10	V
Absolute maximum voltage (temp. sensor)	4.3	V

Mechanical drawing



Test setup

- Camera:** IDS UI3200-SE-M-GL
1.1" 4104 x 3004 px
Pixel size = 3.45 μm
C-mount
- Lens:** LINKHOU TS11-06-160-EL
- Tunable lens:** EL-16-40-TC-VIS-5D-1-C (class 1)
S/N: ANAB3284
- Orientation:** Vertical Optical Axis
- Driver:** Optotune EL-E-4i (Firmware: 1.9.2065, 133899-00-F)
- Target:** USAF chrome target, positive
- Light:** White backlight (LED1-FLS-110x110W)
Red backlight



Field of view with 1.1" sensor

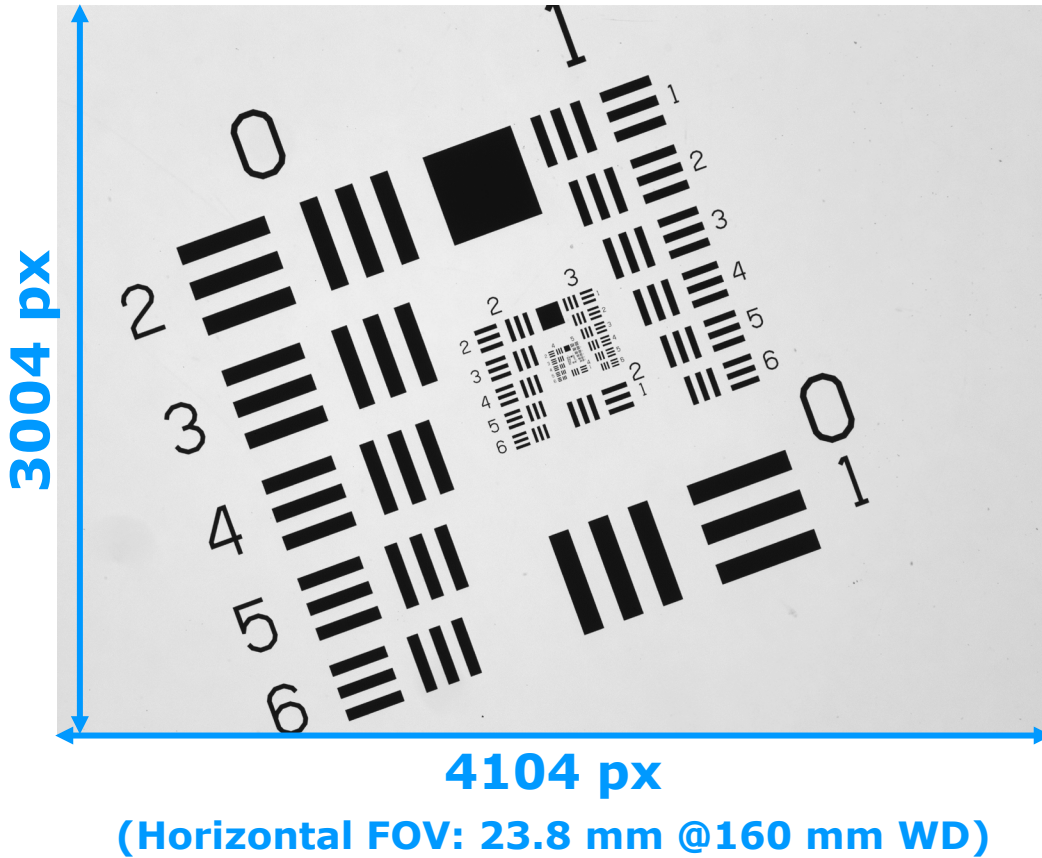
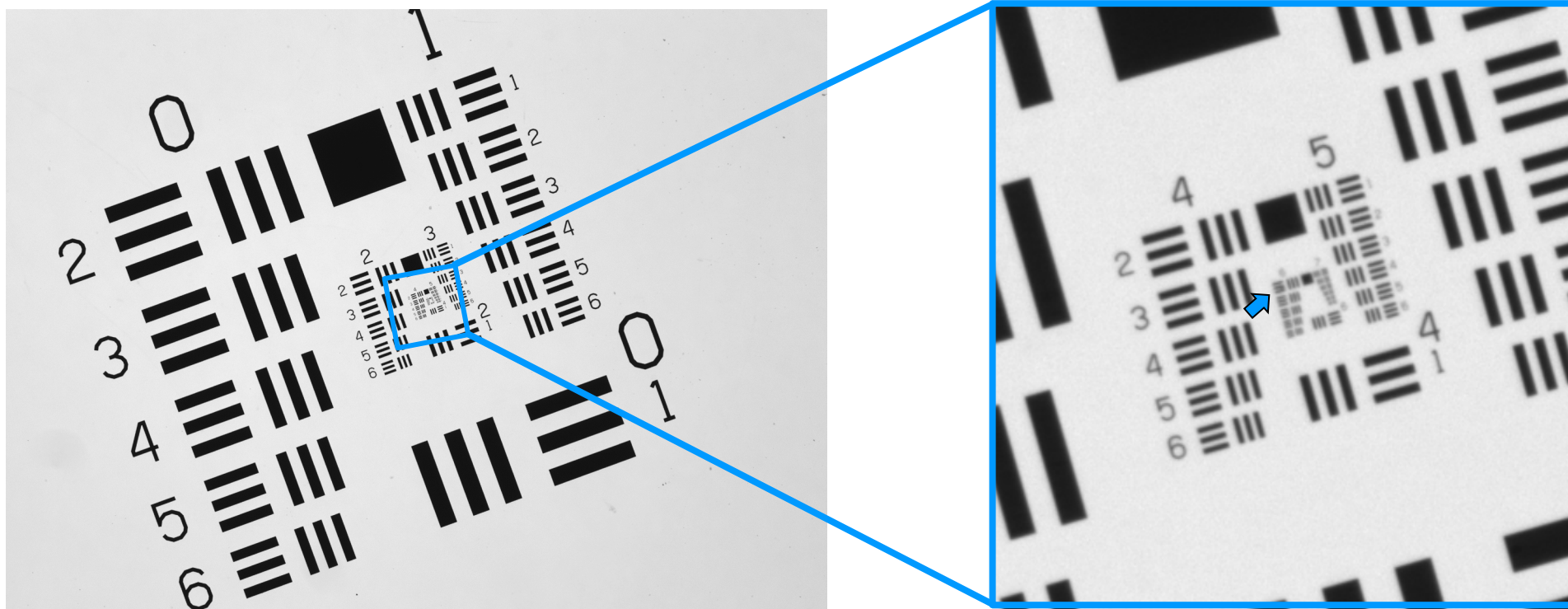


Image size (3.45 μm pixel size):

- Width = 14.2 mm
- Height = 10.4 mm
- Diagonal = 17.6 mm

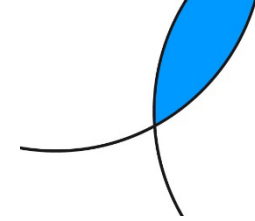
Image evaluation

- All the images are taken at exposure time of 8.2ms, Gain 0, and without gamma correction
- The intensity of illumination is controlled to adjust the histogram of the images
- After acquisition, images are zoomed in to show the resolution-limited element



WD 160 mm: 0 dpt, Red light

Performance is close to Nyquist limit



Camera

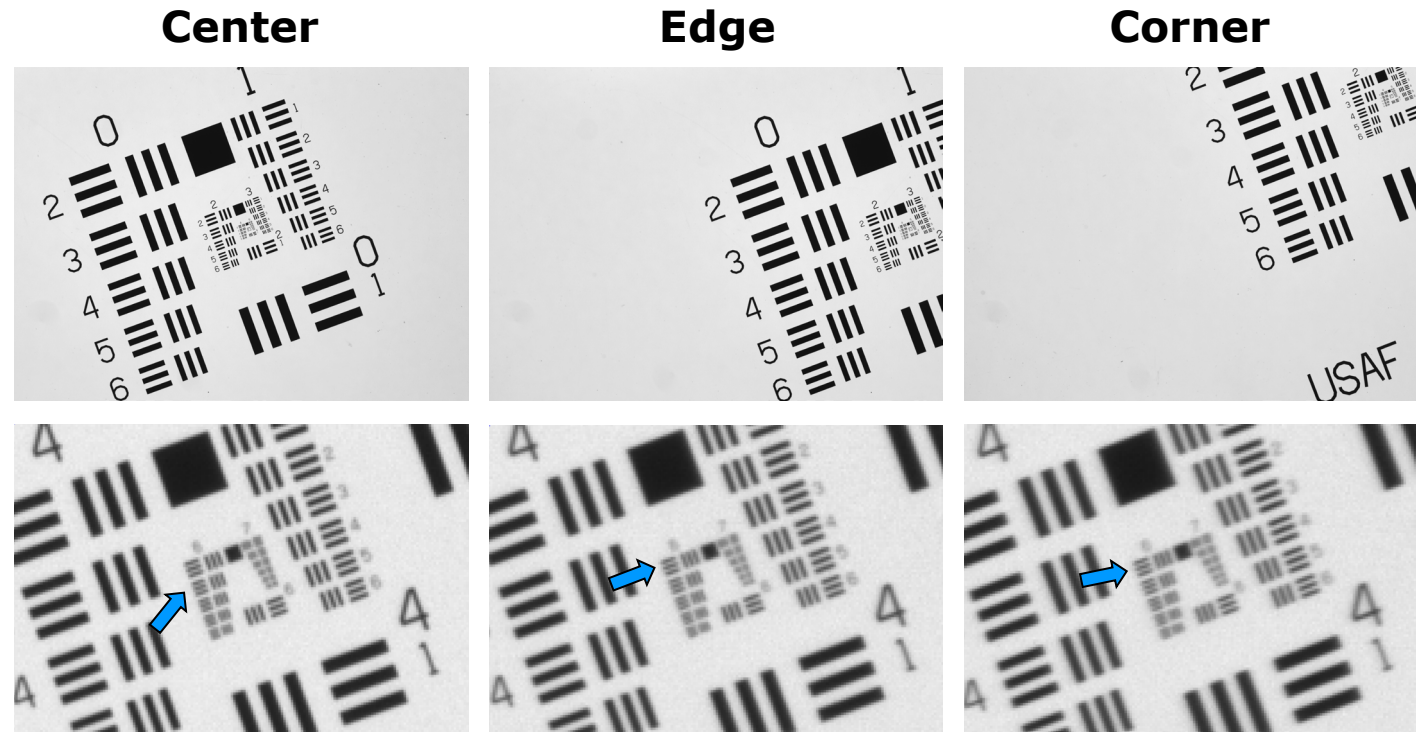
Sensor size = 4104 x 3004 px

Pixel size = 3.45 μm

Nyquist limit = 145 lp/mm

Light

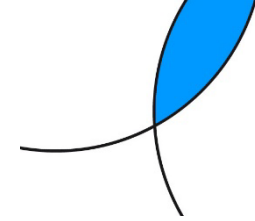
Red background illumination



	Center	Edge	Corner
USAF element:	6/3	6/2	6/2
Line width (μm):	6.2	6.96	6.96
Lp/mm (object):	81	72	72
Magnification:	0.593	0.587	0.583
Lp/mm (image):	136	122	123

WD 144 mm: +2 dpt, Red light

Performance is close to Nyquist limit



Camera

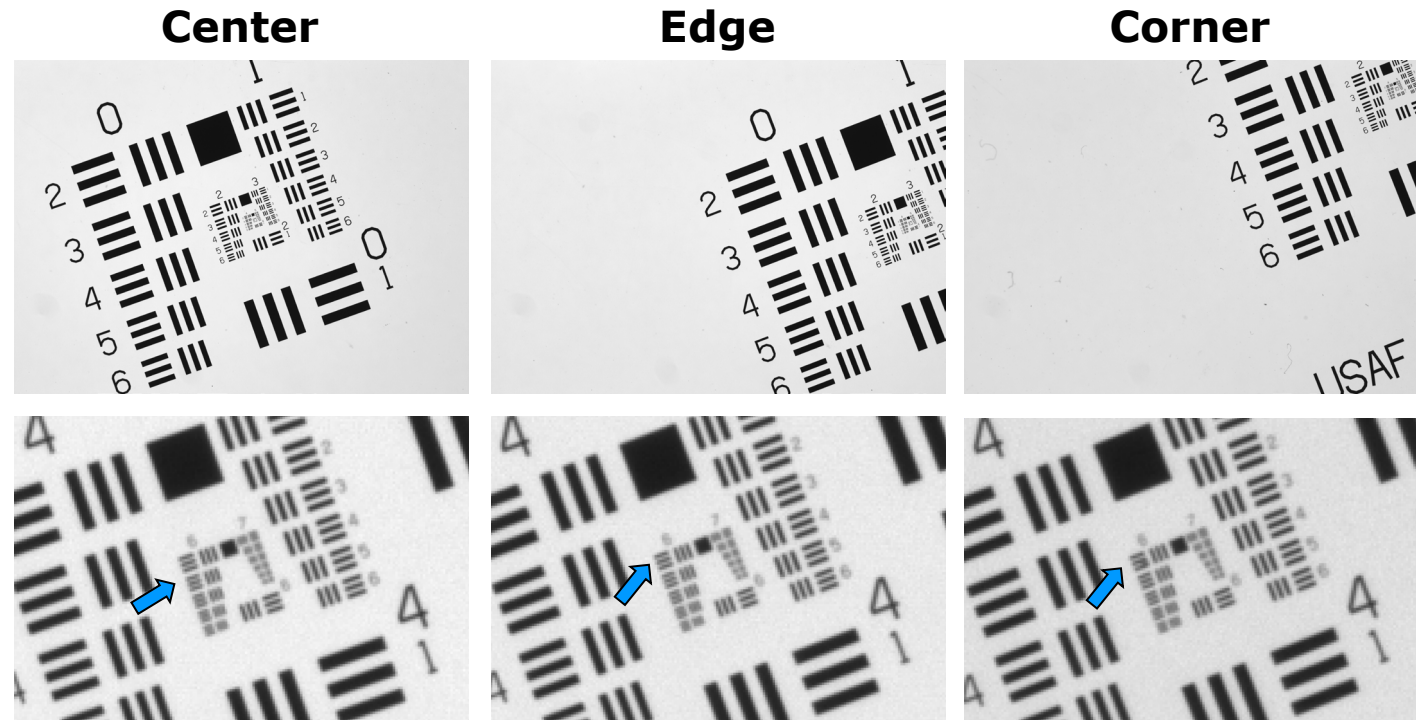
Sensor size = 4104 x 3004 px

Pixel size = 3.45 μm

Nyquist limit = 145 lp/mm

Light

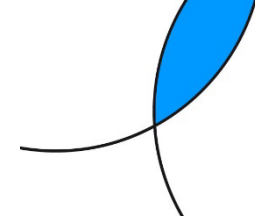
Red background illumination



USAF element:	6/3	6/2	6/2
Line width (μm):	6.2	6.96	6.96
Lp/mm (object):	81	72	72
Magnification:	0.614	0.609	0.605
Lp/mm (image):	131	118	119

WD 178 mm: -2 dpt, Red light

Performance is close to Nyquist limit



Camera

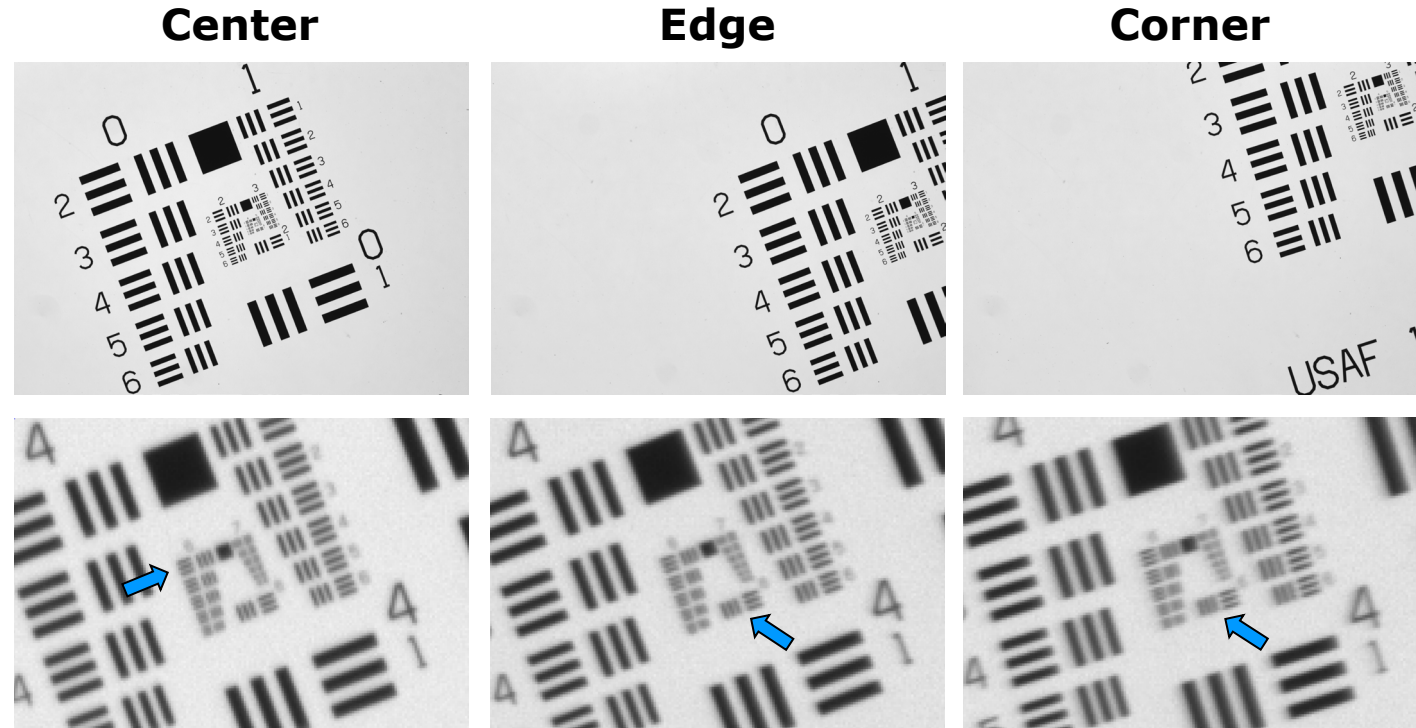
Sensor size = 4104 x 3004 px

Pixel size = 3.45 μm

Nyquist limit = 145 lp/mm

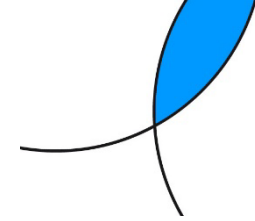
Light

Red background illumination



	Center	Edge	Corner
USAF element:	6/2	6/1	6/1
Line width (μm):	6.96	7.81	7.81
Lp/mm (object):	72	64	64
Magnification:	0.570	0.564	0.559
Lp/mm (image):	126	114	115

WD 160 mm: 0 dpt, White light Performance is close to Nyquist limit



Camera

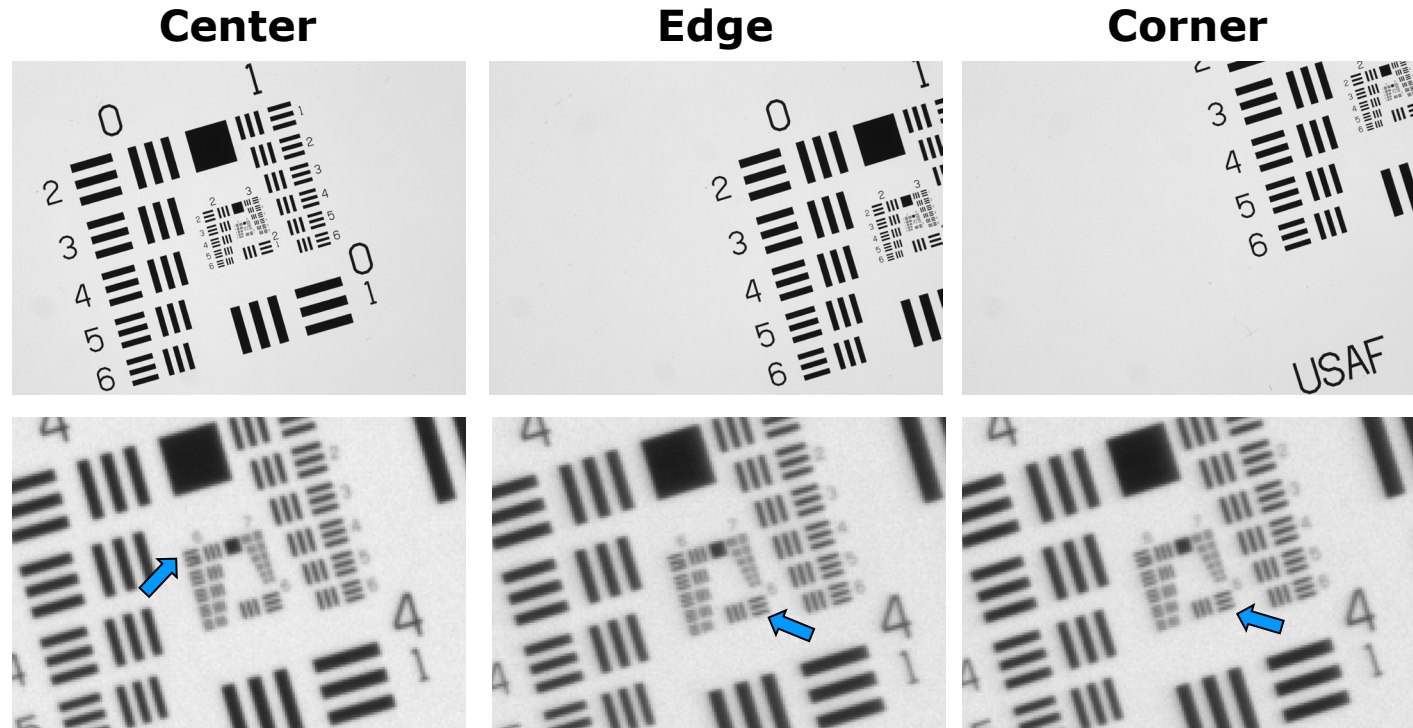
Sensor size = 4104 x 3004 px

Nyquist limit = 145 lp/mm

Pixel size = 3.45 μm

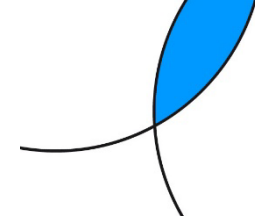
Light

White background illumination



	Center	Edge	Corner
USAF element:	6/2	6/1	6/1
Line width (μm):	6.96	7.81	7.81
Lp/mm (object):	72	64	64
Magnification:	0.591	0.587	0.585
Lp/mm (image):	122	109	109

WD 146 mm: +2 dpt, White light Performance is close to Nyquist limit



Camera

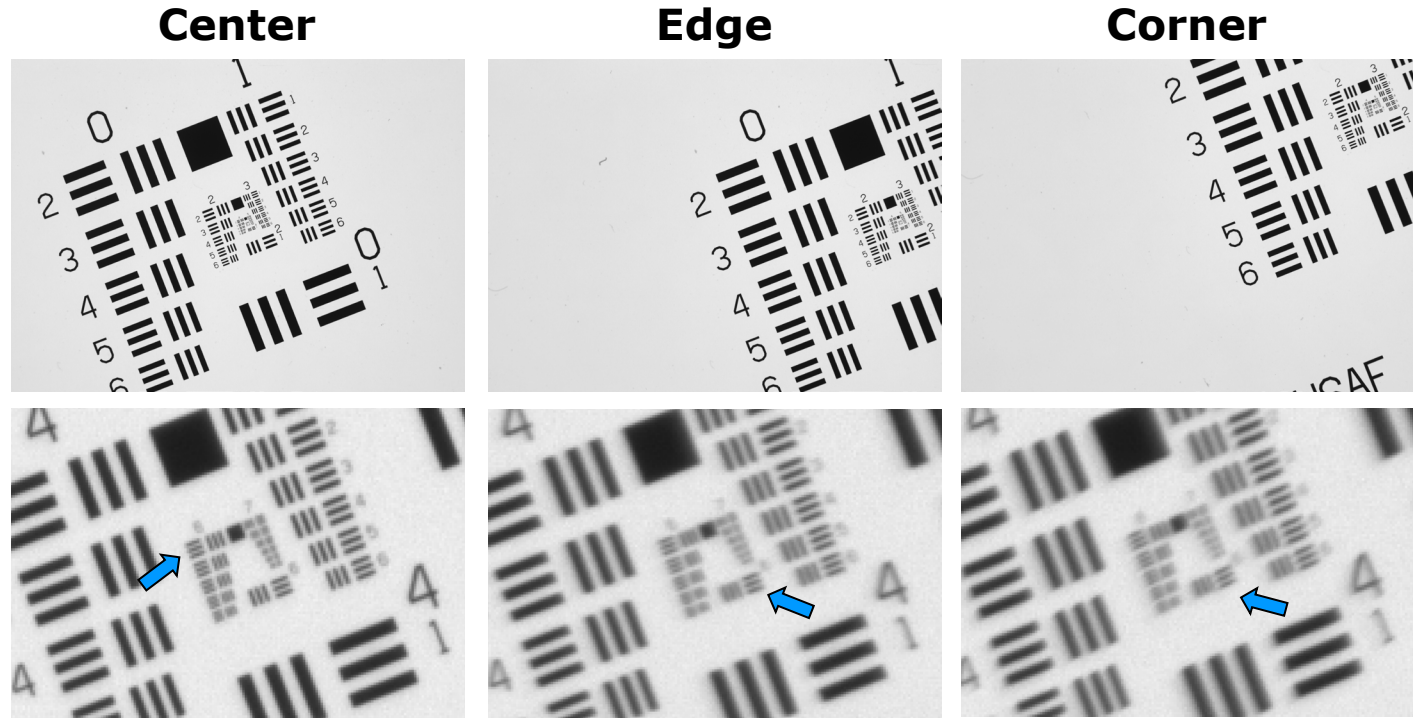
Sensor size = 4104 x 3004 px

Nyquist limit = 145 lp/mm

Pixel size = 3.45 μ m

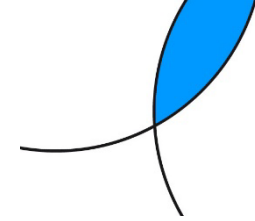
Light

White background illumination



USAF element:	6/2	6/1	6/1
Line width (μ m):	6.96	7.81	7.81
Lp/mm (object):	72	64	64
Magnification:	0.596	0.593	0.590
Lp/mm (image):	121	108	109

WD 180 mm: -2 dpt, White light Performance is close to Nyquist limit



Camera

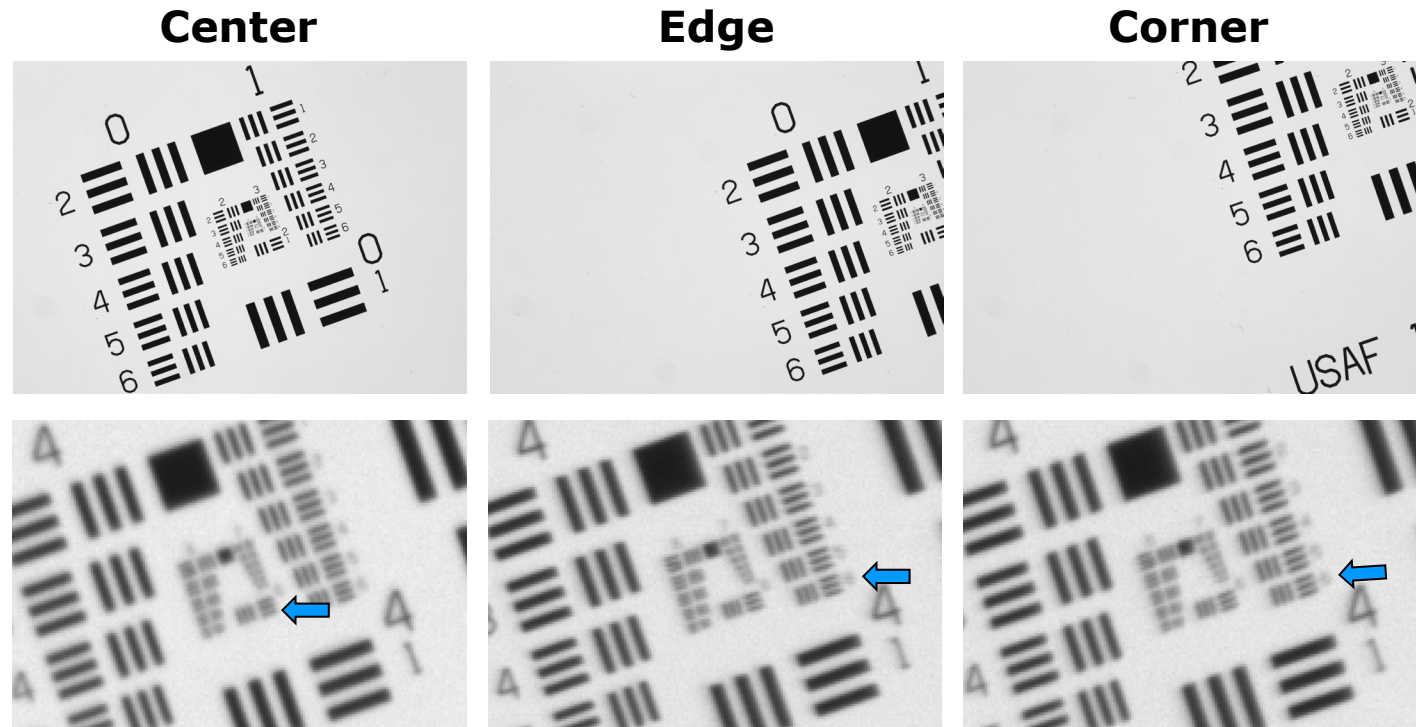
Sensor size = 4104 x 3004 px

Nyquist limit = 145 lp/mm

Pixel size = 3.45 μm

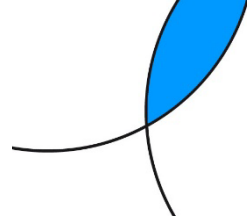
Light

White background illumination

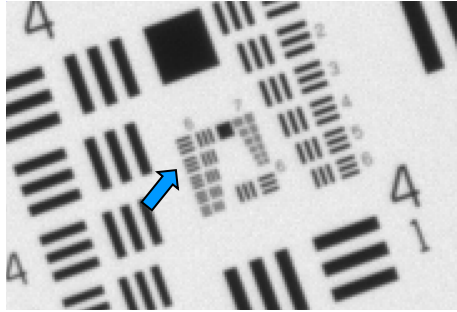
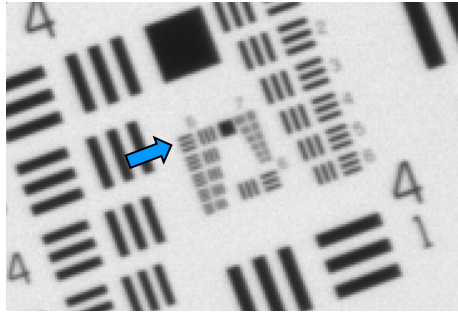
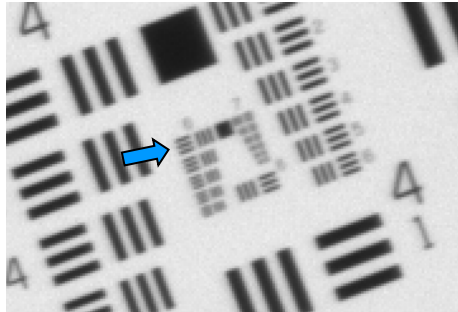
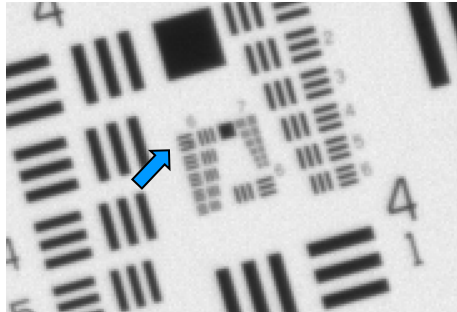
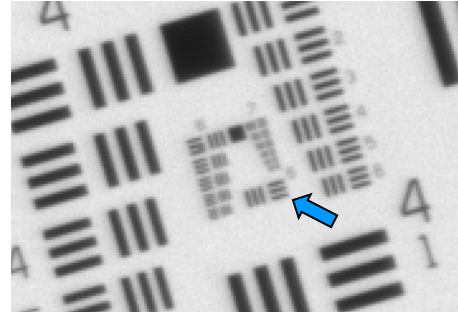
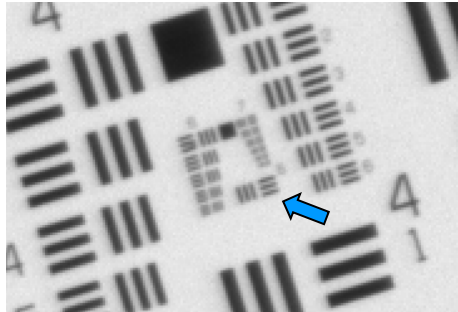


USAF element:	6/1	5/6	5/6
Line width (μm):	7.81	8.77	8.77
Lp/mm (object):	64	57	57
Magnification:	0.565	0.561	0.557
Lp/mm (image):	113	102	102

Polychromatic performance only 10% below monochromatic

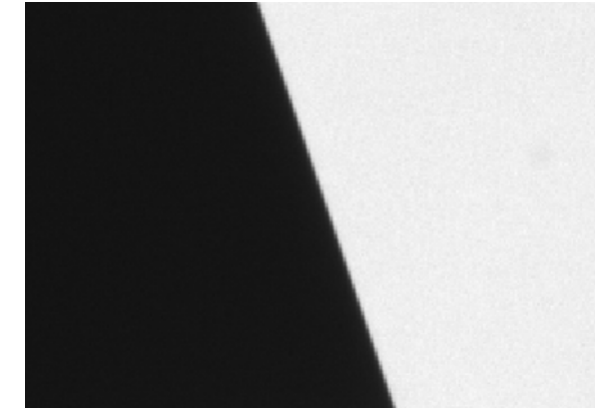
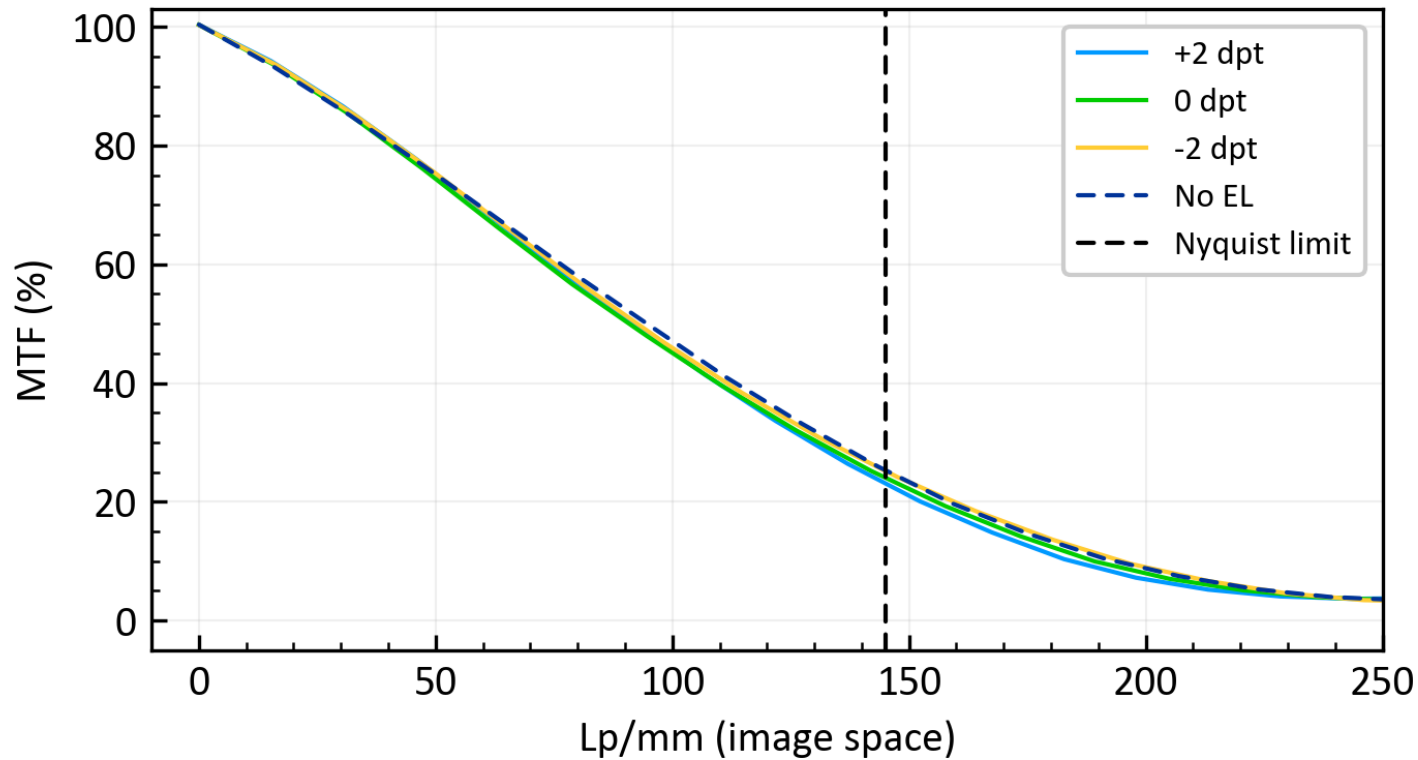


WD 160mm, 0 dpt

	Center	Edge	Corner
Red light			
USAF element:	6/3	6/2	6/2
Line width (um):	6.2	6.96	6.96
Lp/mm (object):	81	72	72
Lp/mm (image):	136	122	122
White light			
USAF element:	6/2	6/1	6/1
Line width (um):	6.96	7.81	7.81
Lp/mm (object):	72	64	64
Lp/mm (image):	122	109	109

MTF evaluation at the center of images

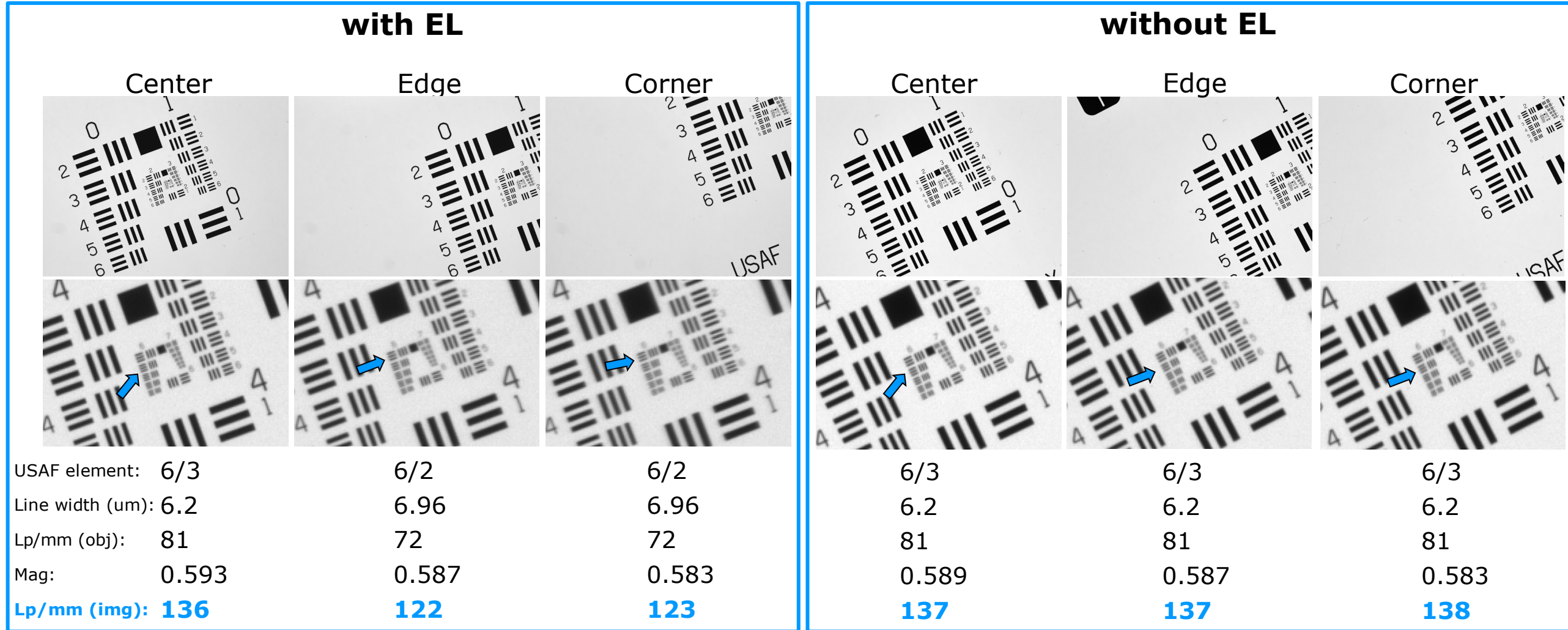
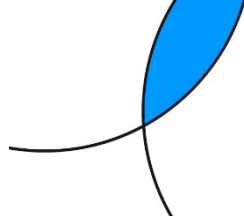
- The MTF measurements are done using monochrome red backlight
- Slanted Edge method is used for MTF calculation using ImageJ plugin
- Datasheet MTF @ 80LP/mm is 58% while the best measured MTF @ 80LP/mm was 55% for the EL @ 0 dpt



MTF @ 80 LP/mm	
Datasheet	58%
No liquid lens	56%
EL @ -2 dpt	55%
EL @ 0 dpt	54%
EL @ +2 dpt	54%

Performance comparison with and without EL

WD 160mm, 0 dpt, Red light



* Images without EL are taken at 7.5ms exposure time to keep the histogram similar.