Test Lab Services Report

Commercial Borescope Image Quality Test

Report ID: SAMPLE03

Requested by:

Customer

Prepared by:

Imatest, LLC

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Contents

Test Capture Setup

Field of View (FOV)

Test Distance: 50 mm
Target: ISO 8600-3 Method A FOV Chart
Device Settings: Defaults, background compensation off
Illumination: Room lights

Procedures for measuring field of view (FOV) are followed in accordance with ISO 8600-3 using the Imatest ISO 8600-3 Method A FOV chart designed for a 50mm capture distance. The setup, shown in Figure 1, consists of the device under test (DUT) mounted on the Imatest Benchtop Test Stand (BTS) using the Endoscope Module V-clamp mounting stage, which allows for vertical adjustment, tilt, and tip. The chart is mounted at a distance of 50 mm from the distal end of the device using the Magnetic Chart Mounting System, which allows for targets to be positioned anywhere on the target plane. The chart is centered within the image field and an image is captured using the device's integrated camera. The FOVs corresponding with largest visible circles in the vertical, horizontal, and diagonal directions are recorded in degrees.

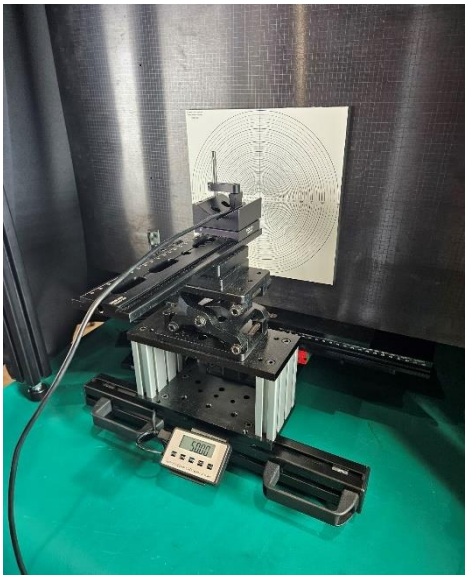

Figure 1

Sharpness and MTF

Test Distance: 50 mm
Target: Checkerboard Chrome on Glass Target 2", 7x7 4mm squares
Device Settings: Defaults, background compensation off
Illumination: Imatest Size B 10000 Lux LED Lightbox; 7930 Lux; 6476 CCT (D65)

Procedures for measuring sharpness and modulation transfer function (MTF) are based on ISO 8600-5, but altered for use on a semi-rigid device with an integrated sensor and optics. The DUT is mounted on the test stand using a V-clamp. The Imatest LED lightbox is mounted to the Z-stage of the Benchtop Test Stand and set to maximum intensity and color temperature, which corresponds with standard illuminant D65. The flatfield illumination (without the chart) is characterized for a distance of 50mm from the lightbox surface using a spectrophotometer, yielding an illuminance of 7930 lux, an irradiance of 29.85 W/m^2, and a correlated color temperature (CCT) of 6476 K.

In a dark environment, the checkerboard target is mounted to the lightbox and set to a distance of 50mm from the distal end of the device. The checkerboard is aligned to capture vertical and horizontal slanted edges at the on-axis and various off-axis image points, as specified in the standard. Additional off-axis points (C1 and C2 in Figure 2) are captured to accommodate the rectangular image field.

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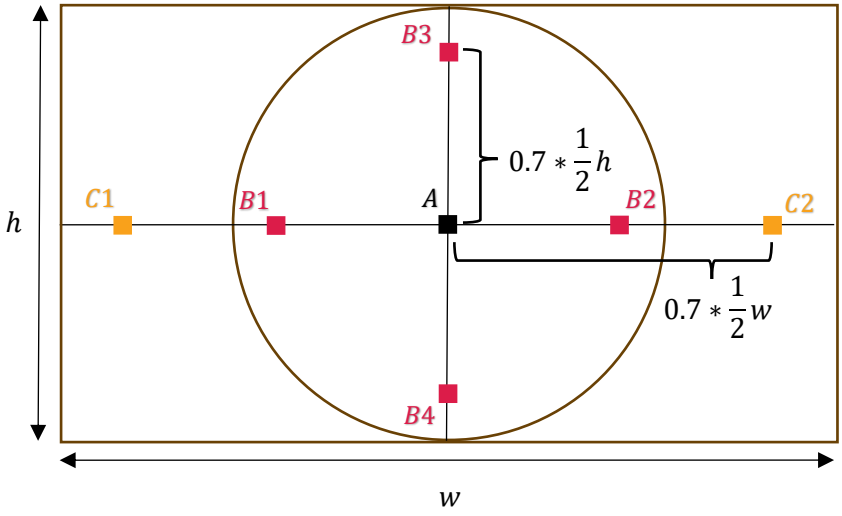

Figure 2

Points B1-B4 are located at 70% of the image height from the central point A. Additional points C1 and C2 are at 70% of the image width from the image center. The central saddle point of the checkerboard, indicated by fiducial marks, is aligned with each of these points, such that both a horizontal and vertical slanted edge near these points can be extracted for analysis. Images are captured for each of these points, shown in Figure 3, to determine the on-axis, off-axis, and far off-axis sharpness.

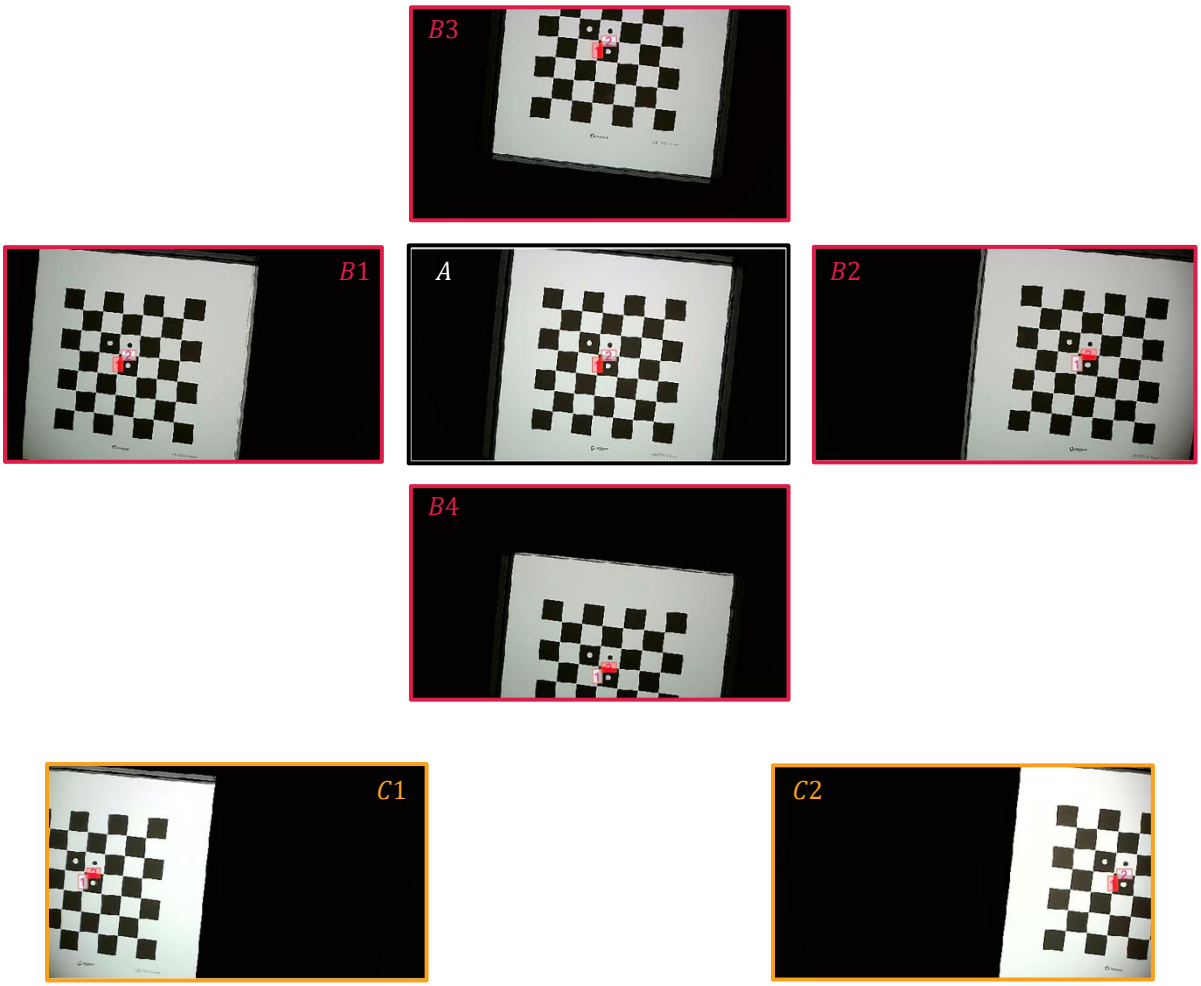

Figure 3

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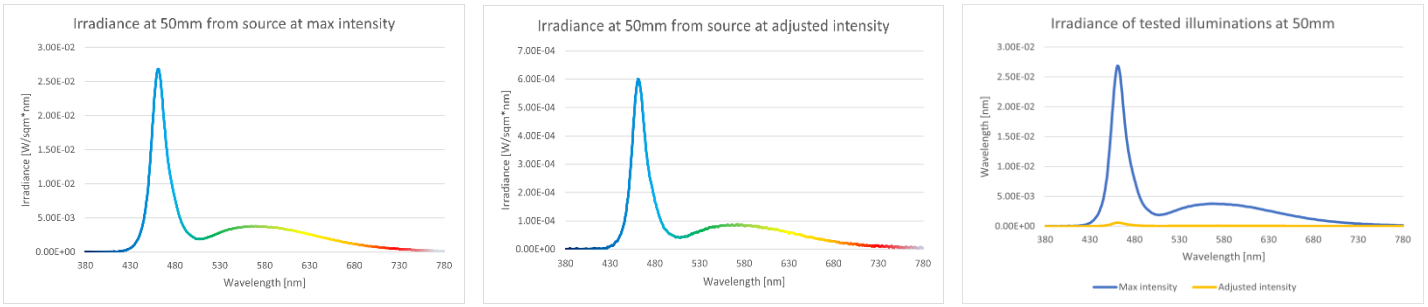
Color Accuracy

Test Distance: 50 mm
Target: ColorGauge Nano
Device Settings: Defaults, background compensation off
Illumination: Integrated LEDs; Maximum intensity 255 lux; Adjusted intensity 5.7 lux

Images of the ColorGauge Nano centered in the image frame are captured at 50mm under illumination of the 6 integrated dimmable LEDs on the perimeter of the device's distal end to more accurately represent the conditions in which the device is likely to be used. Images are taken at two light intensities: 1) maximum intensity (255 lux at 50mm), and 2) saturation adjustment (greatest illumination without saturating any of the color channels; 5.7 lux at 50mm). A spectrophotometer is used to measure the spectra of each illumination at a 50mm distance, shown in Figures 4a-4c.



a) *b)* *c)*

Figure 4

Uniformity

Test Distance: 50 mm
Target: Imatest 10,000 Lux LED Lightbox
Device Settings: Defaults, background compensation off
Illumination: Imatest Size B 10000 Lux LED Lightbox; 7930 Lux; 6476 CCT (D65)

Flatfield images are captured at a distance of 50mm from the surface of the Imatest LED Lightbox to the distal end of the device. The size B lightbox has a uniformity of 95%, and is set to maximum output intensity and CCT, which corresponds to a measured illuminance of 7930 lux, irradiance of 29.85 W/m^2, and CCT of 6476 K at a 50mm test distance. The illuminated field fills the image frame, and 10 images are captured and averaged for analysis.

Distortion

Test Distance: 50 mm
Target: Checkerboard Photographic Multi-Size Test Chart
Device Settings: Defaults, background compensation off
Illumination: Aputure Light Storm LS 1c LED Lights (2); D65; 550 lux at chart surface

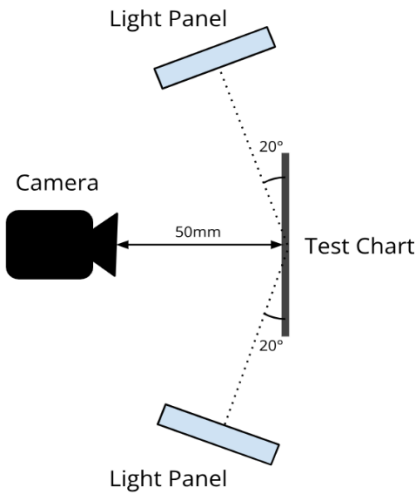


Figure 5

The Checkerboard Multi-Size Reflective Test Chart is mounted on the Imatest Benchtop Test Stand using the magnetic chart mounting system at a distance of 50mm from the distal end of the device. The central saddle point of the 4mm frequency chart, indicated by fiducial marks, is aligned with the center of the image field. The chart is illuminated with D65 light by two Aputure Light Storm LS 1c LED Light Panels using a standard lighting configuration to reduce glare, as depicted in Figure 5. The illumination measured at the chart surface is 550 lux. An image of the checkerboard target is captured using the integrated camera sensor for analysis.

Analysis Results and Observations

Field of View (FOV)

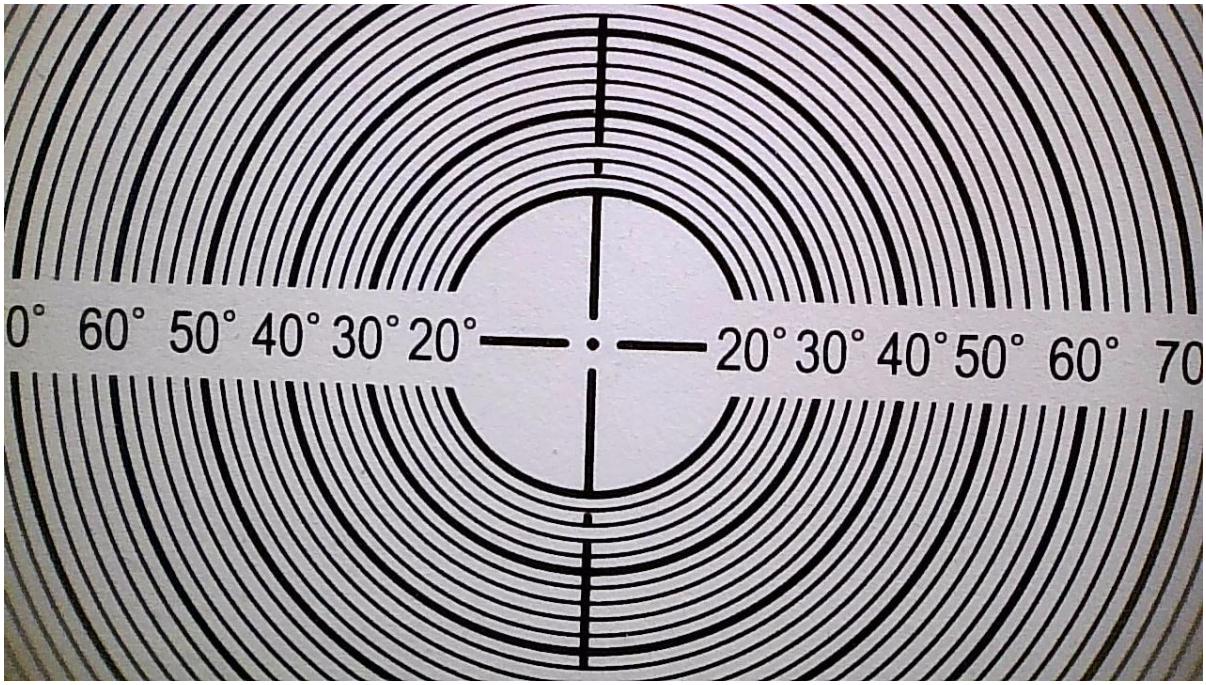


Figure 6

ISO 8600-3 Method A is followed to find the FOV of the device. The FOV is determined by the largest circle visible within the image frame. For non-circular images, such as that captured by the device shown in Figure 6, the segments of the largest visible circle are considered.

Direction	Measured FOV	Specified FOV
Horizontal	71°	66°
Vertical	43°	unspecified
Diagonal	79°	unspecified

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MTF and Sharpness

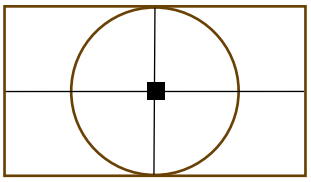
Procedures, measurements, and analyses for resolution are based on ISO 8600-5:2020, but are altered for use by integrated systems. This section of the standard is intended to test the optical resolution of the coupling optics with the use of a separate monochromatic camera of known spectral response. However, the DUT uses an integrated RGB sensor, and cannot output raw (linear) unprocessed data, and therefore does not meet the camera requirements under Section D.4 of the standard. The same basic measurements and analyses can still be applied to camera-integrated endoscopes to give insight into the quality of images produced by the full sensor/lens/processing system.

Edge and MTF

Sharpness determines the amount of detail an imaging system can reproduce. It is defined by the boundaries between zones of different tones or colors. Image sharpness can be measured by the “rise distance” of an edge within the image. With this technique, sharpness can be determined by the distance of a pixel level between 10% to 90% of its final value. This technique is applied to the horizontal and vertical edges extracted from the checkerboard images taken for each point of interest in the image field, previously shown in Figure 2, and corresponding edge profile plots are shown for each edge in the following analyses. The modulation transfer function (MTF), which is the relative contrast at a given spatial frequency (output contrast/input contrast), is also calculated and plotted for each edge. High spatial frequencies correspond to fine image detail. MTF50P, which is the spatial frequency where contrast drops to half its peak value, and the MTF Area are also reported for each edge. Because none of the analyzed edges have a peak MTF of 1 and are not over sharpened, higher MTF50P values allude to better image quality.

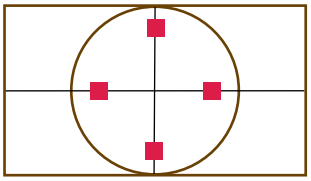
On-Axis (Point A)

	Horizontal Edge Results	Vertical Edge Results
10-90% Rise	1.93 px	2.02 px
Peak MTF	1.00	1.00
MTF50P	0.26 C/P	0.25 C/P
MTF Area	0.29 C/P	0.28 C/P



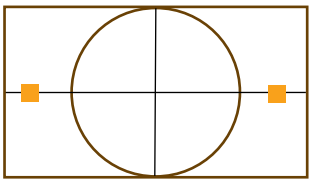
Off-Axis (Points B1-B4 Averaged)

	Horizontal Edge Results	Vertical Edge Results
10-90% Rise	2.14 px	1.91 px
Peak MTF	1.00	1.00
MTF50P	0.27 C/P	0.30 C/P
MTF Area	0.28 C/P	0.31 C/P

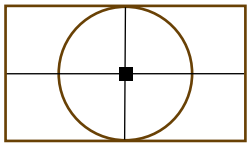


Wide Off-Axis (Points C1-C2 Averaged)

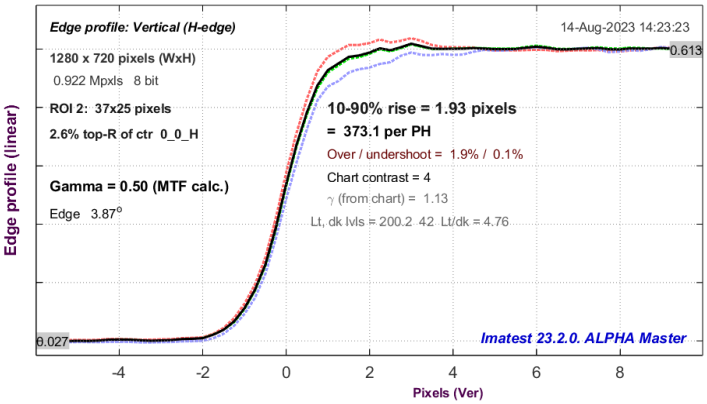
	Horizontal Edge Results	Vertical Edge Results
10-90% Rise	1.54 px	1.93 px
Peak MTF	1.00	1.00
MTF50P	0.36 C/P	0.27 C/P
MTF Area	0.34 C/P	0.29 C/P

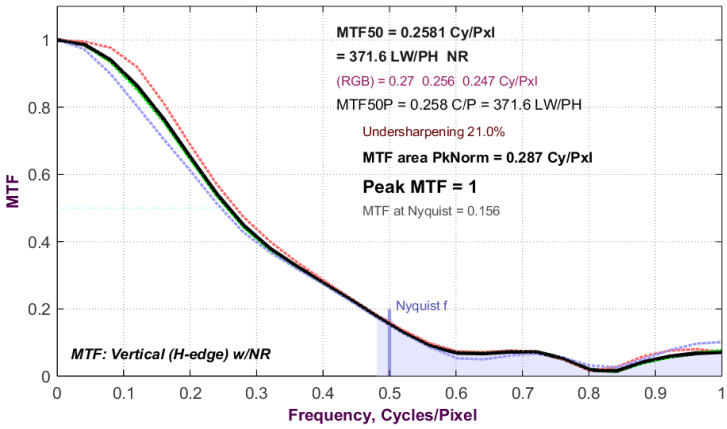


On-Axis Edge and MTF (Point A)

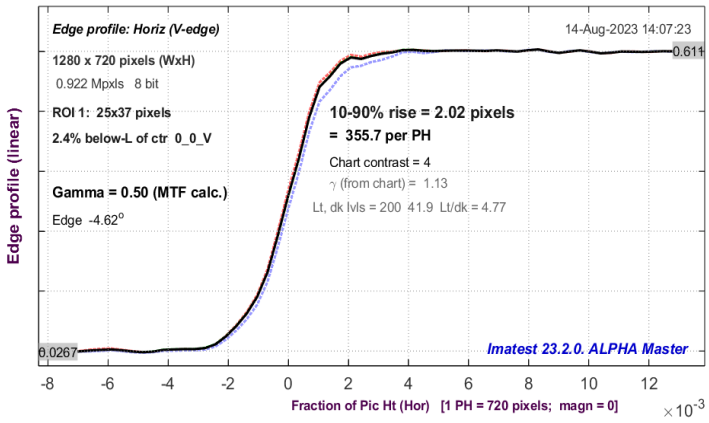


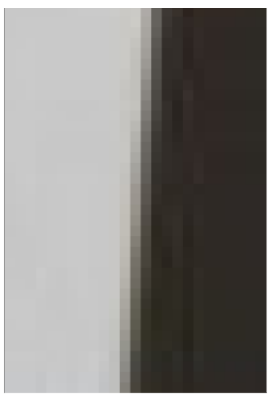
Horizontal Edge Results	
10-90% Rise	1.93 px
Peak MTF	1.00
MTF50P	0.26 C/P
MTF Area	0.29 C/P

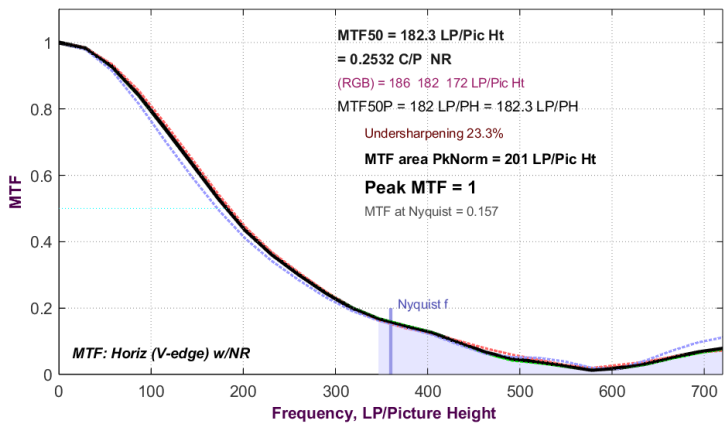


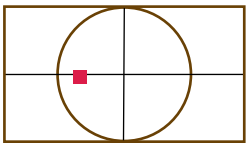


Vertical Edge Results	
10-90% Rise	2.02 px
Peak MTF	1.00
MTF50P	0.25 C/P
MTF Area	0.28 C/P



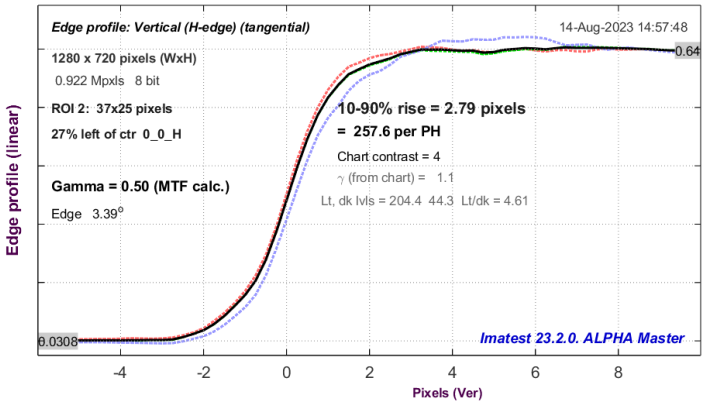


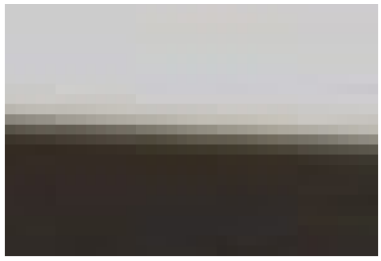


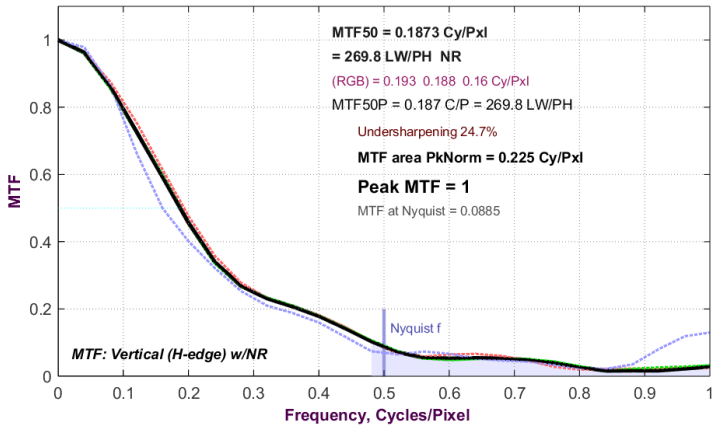


Off-Axis Edge and MTF (Point B1)

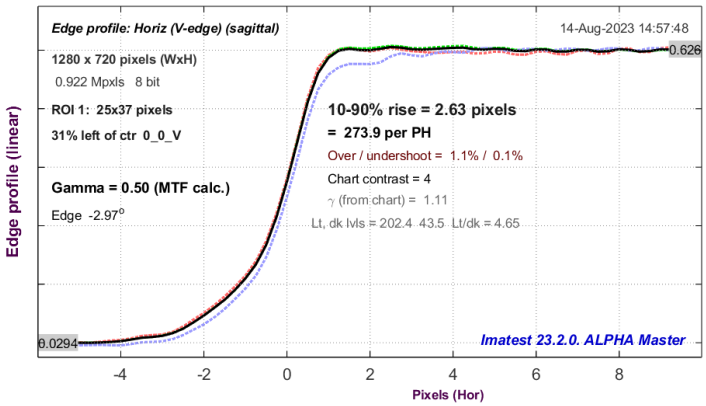
Horizontal Edge Results	
10-90% Rise	2.79 px
Peak MTF	1.00
MTF50P	0.19 C/P
MTF Area	0.23 C/P

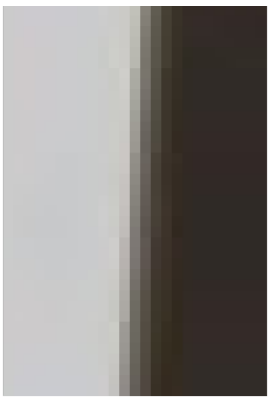


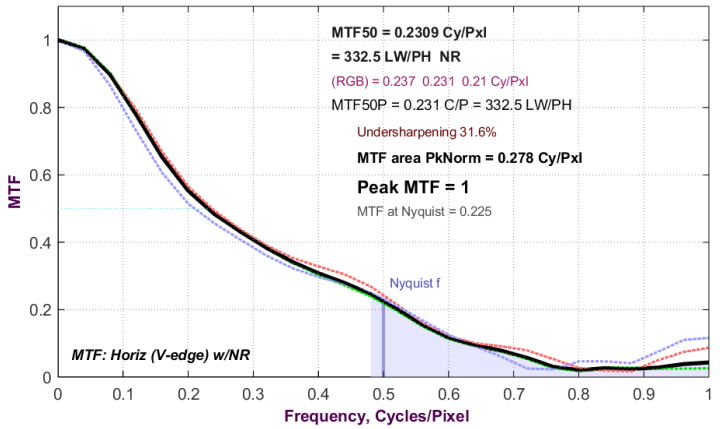




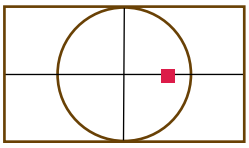
Vertical Edge Results	
10-90% Rise	2.63 px
Peak MTF	1.00
MTF50P	0.23 C/P
MTF Area	0.28 C/P



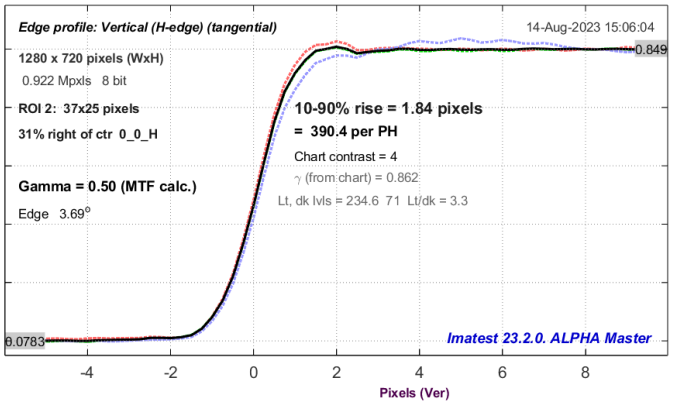


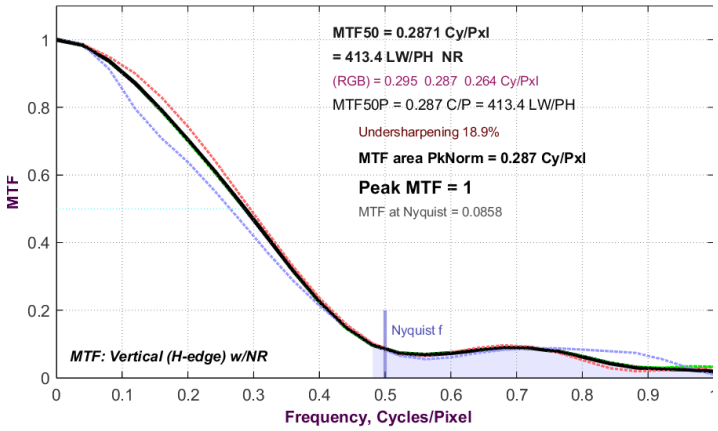


Off-Axis Edge and MTF (Point B2)

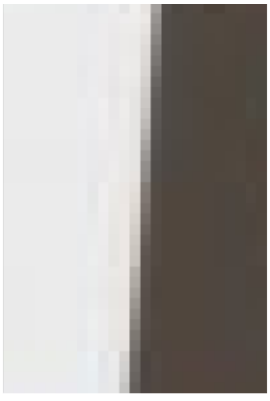


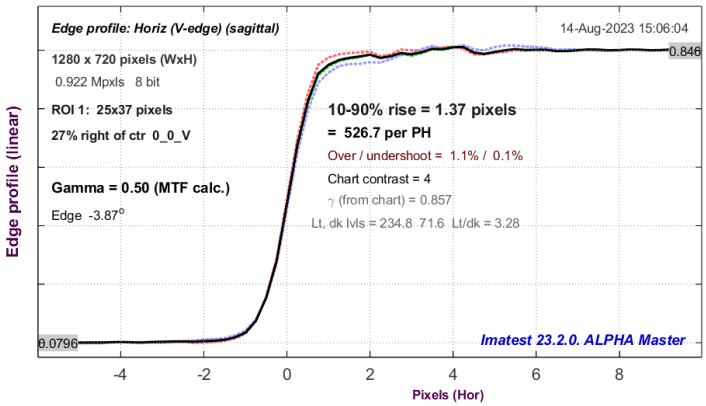
Horizontal Edge Results	
10-90% Rise	1.84 px
Peak MTF	1.00
MTF50P	0.29 C/P
MTF Area	0.29 C/P

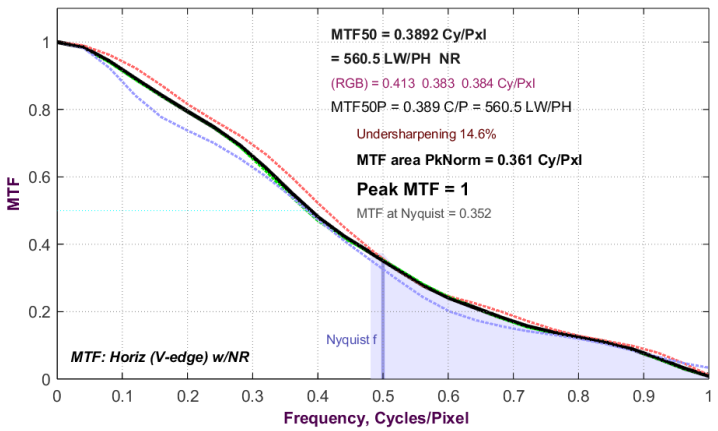


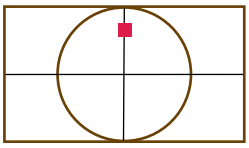


Vertical Edge Results	
10-90% Rise	1.37 px
Peak MTF	1.00
MTF50P	0.39 C/P
MTF Area	0.36 C/P



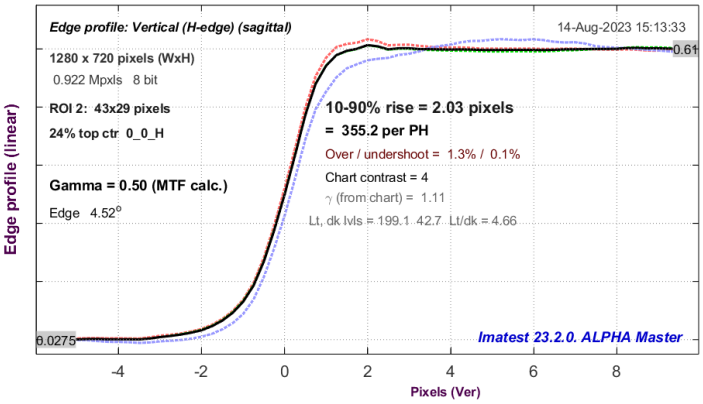


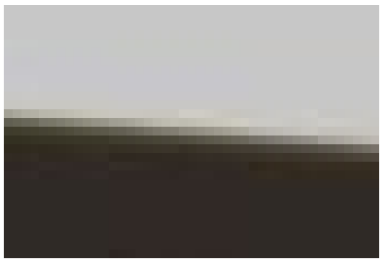


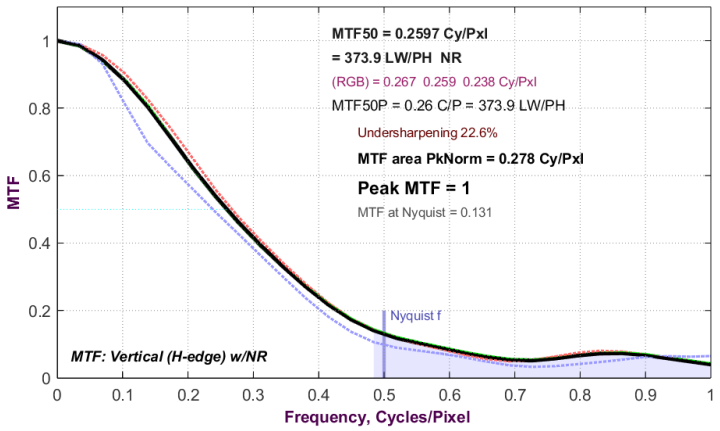


Off-Axis Edge and MTF (Point B3)

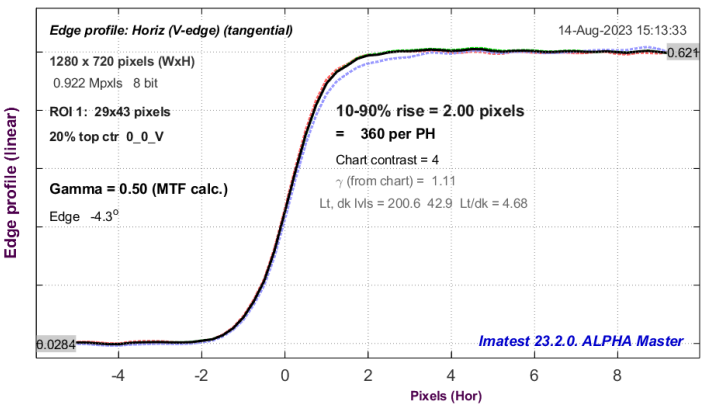
Horizontal Edge Results	
10-90% Rise	2.03 px
Peak MTF	1.00
MTF50P	0.26 C/P
MTF Area	0.28 C/P

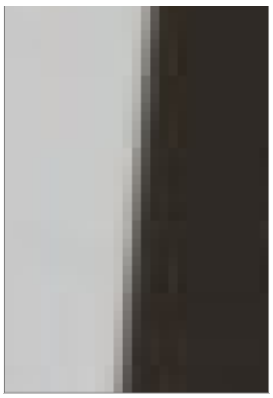


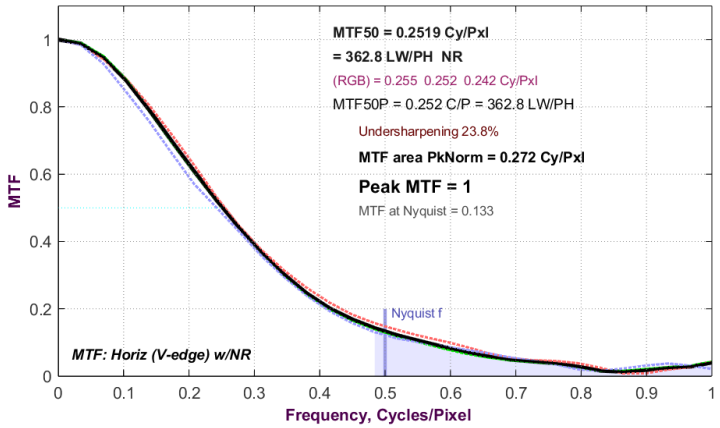




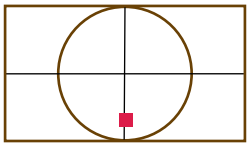
Vertical Edge Results	
10-90% Rise	2.00 px
Peak MTF	1.00
MTF50P	0.25 C/P
MTF Area	0.27 C/P



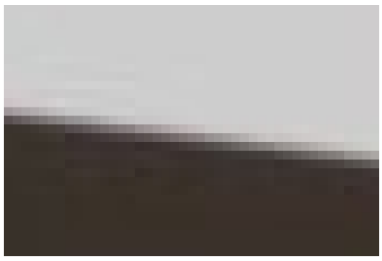


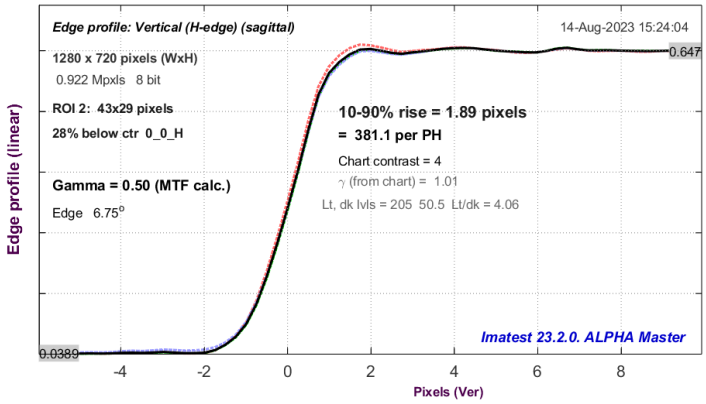


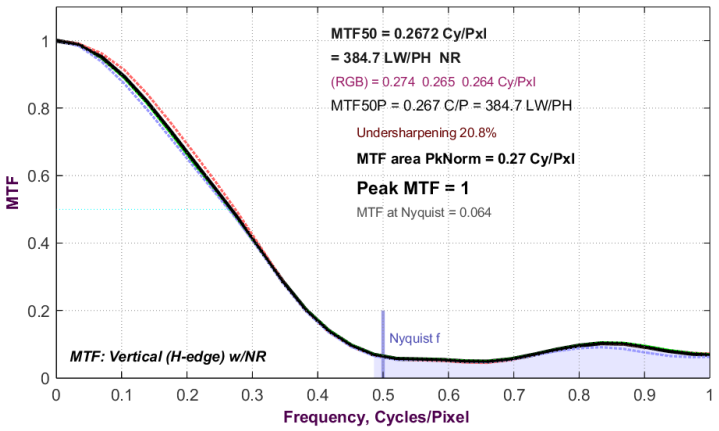
Off-Axis Edge and MTF (Point B4)



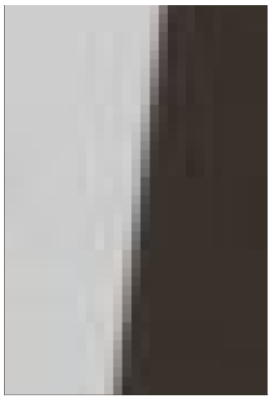
Horizontal Edge Results	
10-90% Rise	1.89 px
Peak MTF	1.00
MTF50P	0.27 C/P
MTF Area	0.27 C/P

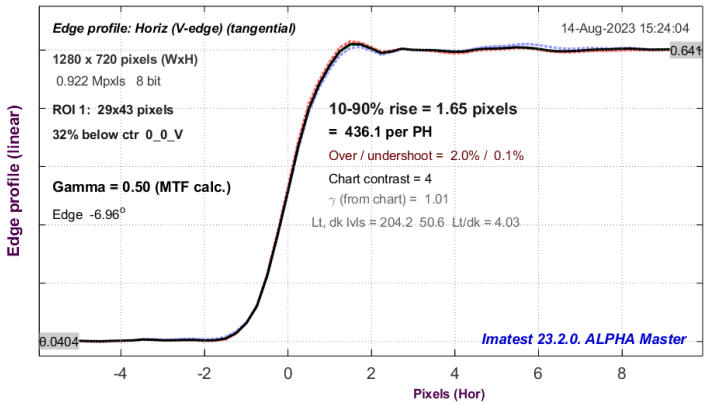


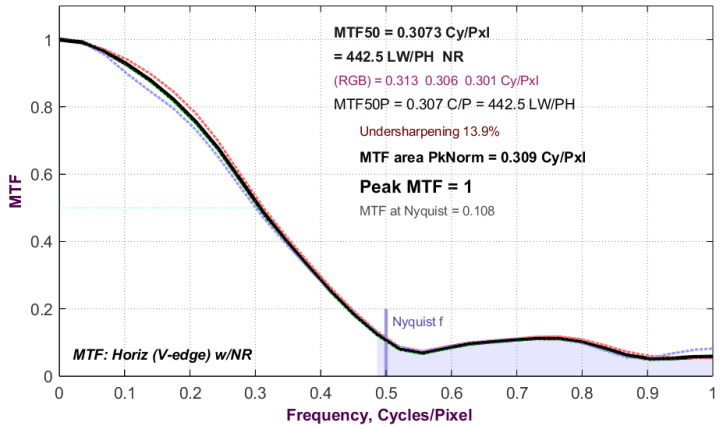




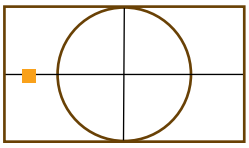
Vertical Edge Results	
10-90% Rise	1.65 px
Peak MTF	1.00
MTF50P	0.31 C/P
MTF Area	0.31 C/P



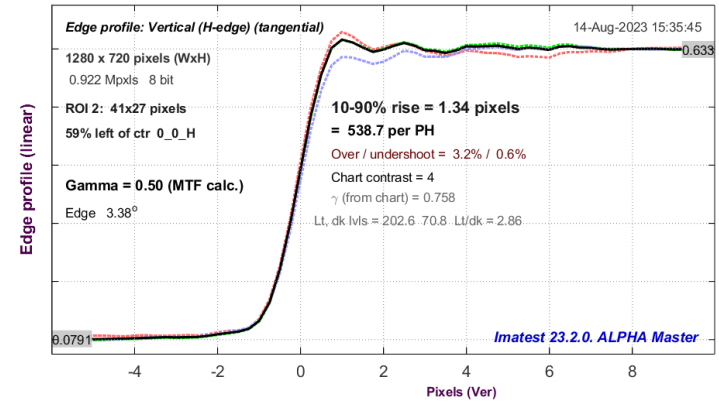


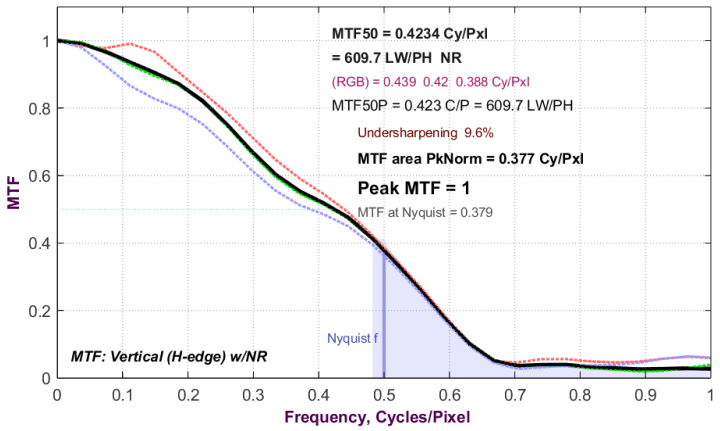


Off-Axis Edge and MTF (Point C1)

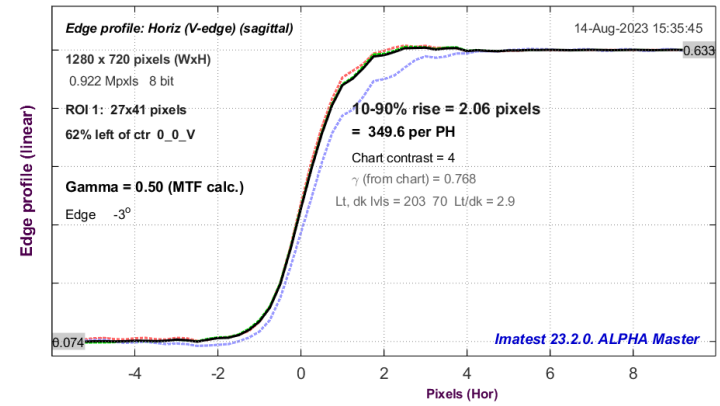


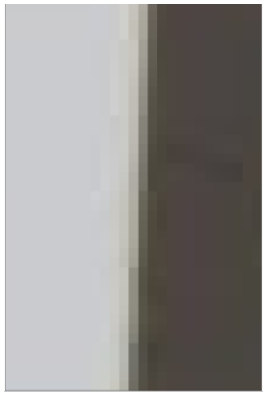
Horizontal Edge Results	
10-90% Rise	1.34 px
Peak MTF	1.00
MTF50P	0.42 C/P
MTF Area	0.38 C/P

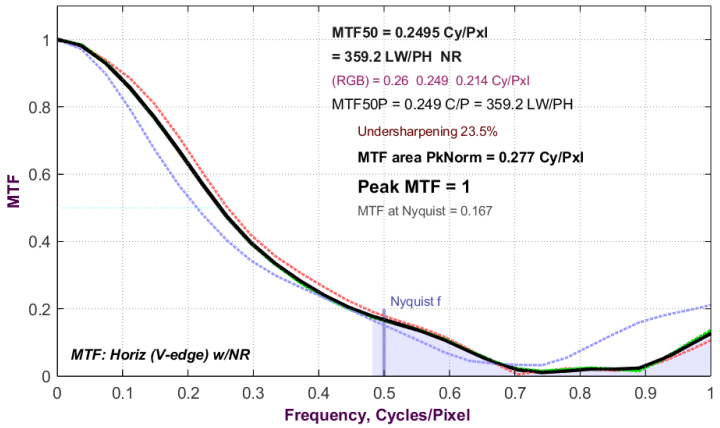


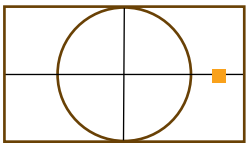


Vertical Edge Results	
10-90% Rise	2.06 px
Peak MTF	1.00
MTF50P	0.25 C/P
MTF Area	0.28 C/P



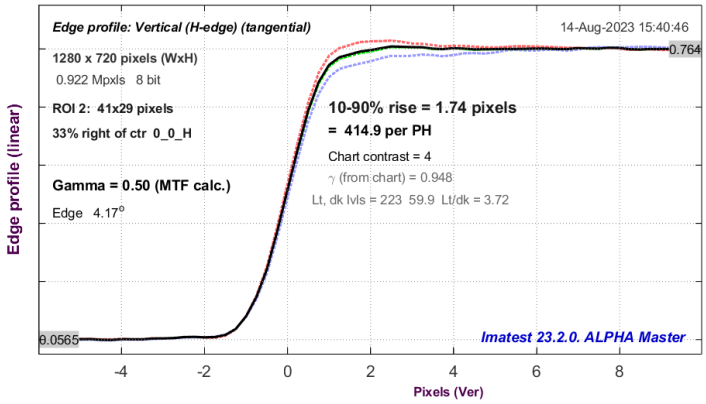


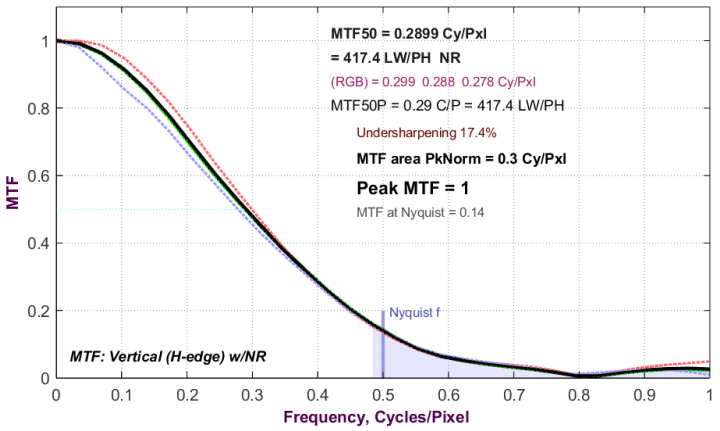




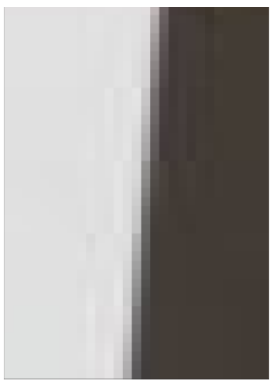
Off-Axis Edge and MTF (Point C2)

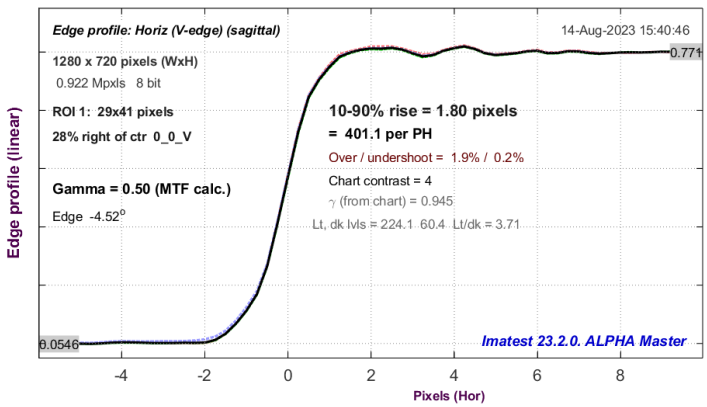
Horizontal Edge Results	
10-90% Rise	1.74 px
Peak MTF	1.00
MTF50P	0.29 C/P
MTF Area	0.30 C/P

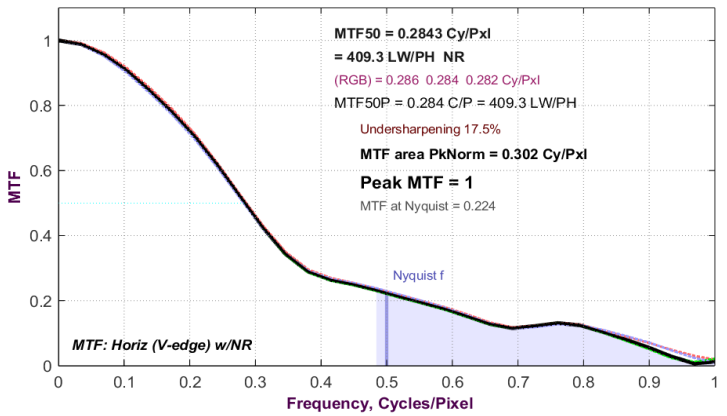




Vertical Edge Results	
10-90% Rise	1.80 px
Peak MTF	1.00
MTF50P	0.28 C/P
MTF Area	0.30 C/P







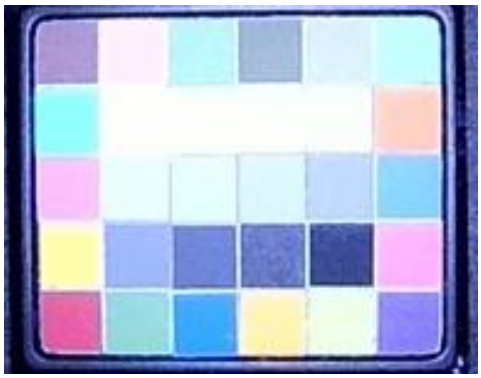
Color Accuracy

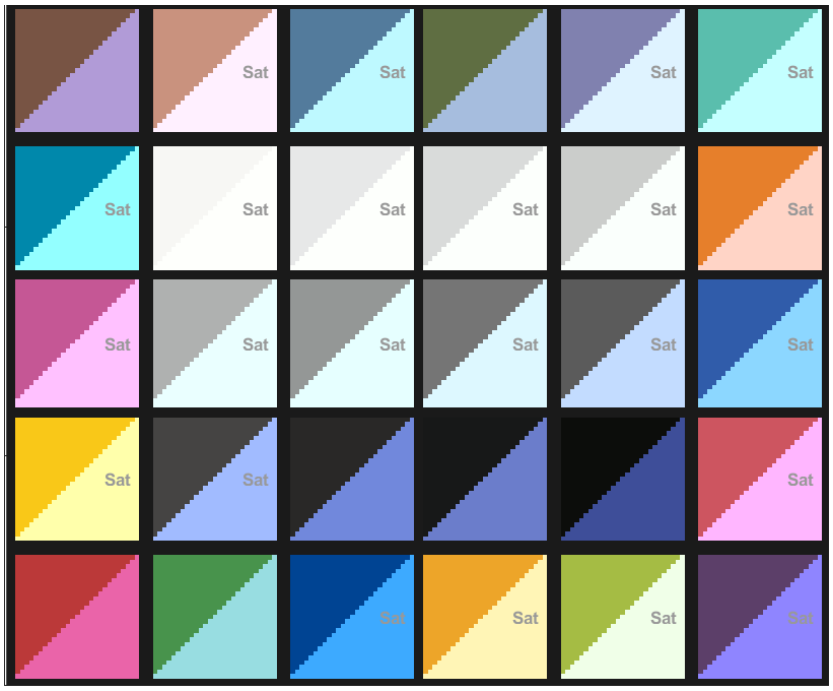
Color accuracy metrics are calculated from the images captured of the ColorGauge Nano under the two illuminations specified in the lab setup. This target has the identical 18 color patches as the Calibrite™ ColorChecker®, plus 12 spectrally neutral gray patches to assess correct exposure and white balance in close-up or macro photography applications, and is used to calculate common color metrics, ΔE and ΔC, chroma noise, and color shift.

Results from the image data captured at maximum intensity of the light source reveals extreme saturation at a distance of 50mm. There is a particularly high response from the blue channel, which can be attributed to, at least in part, the high concentration of blue light in the LED spectra, which contains a significant peak at 460nm, as shown in Figure 4. As a result, calculated color errors are large and a severe decrease in radii in the HSV plot signifies oversaturation.

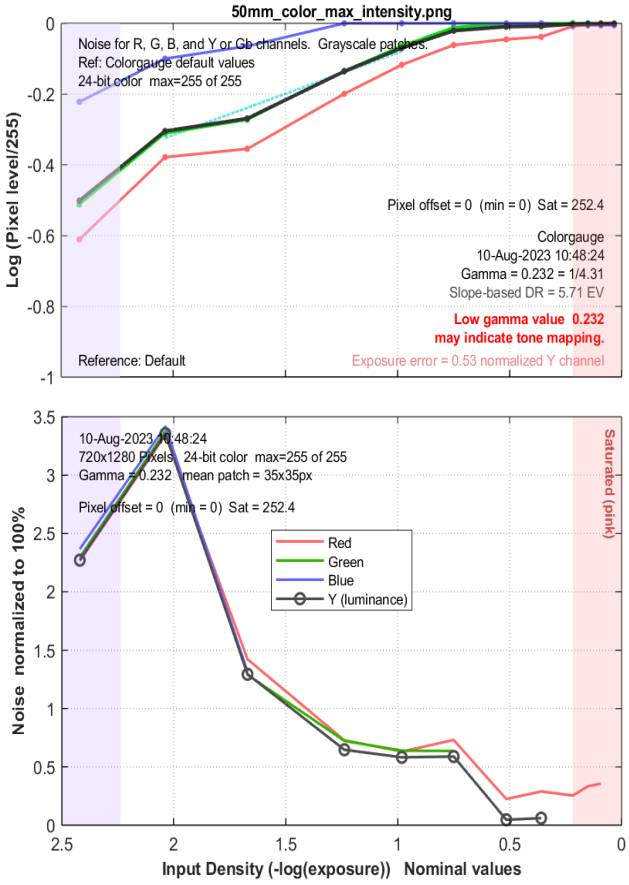
A second measurement captured at 5.7 lux was obtained to determine the color accuracy without any saturated patches. This was done by adjusting the light source to the maximum intensity at which none of the color channels were saturated. Due to the effects of the blue-dominant wavelengths in the illuminant spectra, the blue channel was quick to saturate, requiring a significantly lower light intensity in order to prevent saturation. This also still results in relatively large color errors, and a very evident hue shift towards blue, particularly for the neutral patches, revealing overall poor color reproduction.

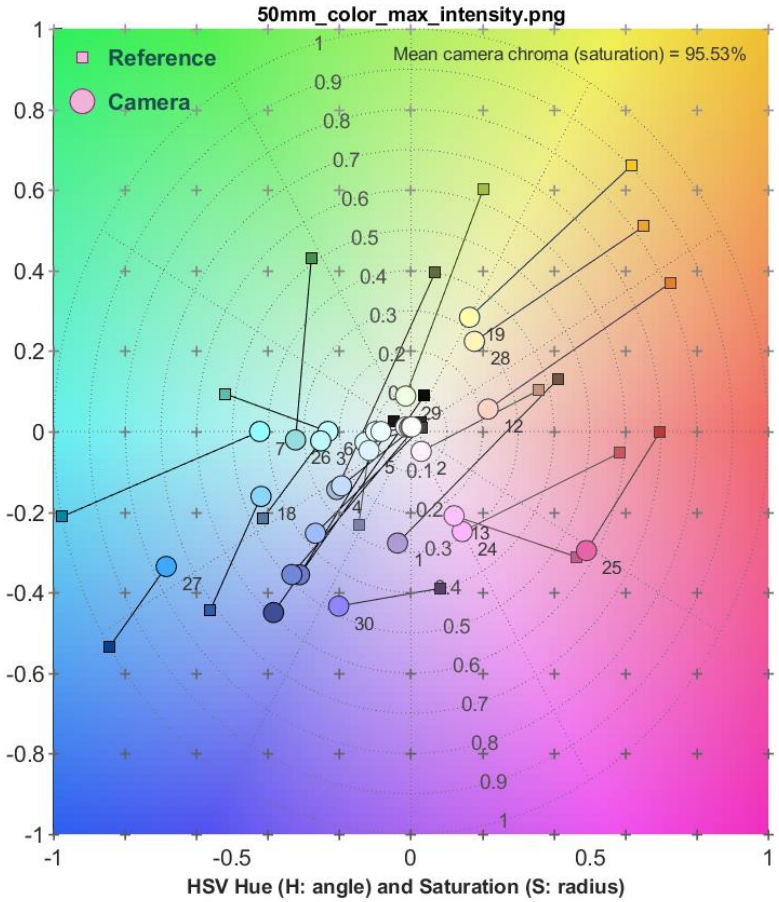
Illumination 1: Maximum Intensity (255 Lux) @ 50mm Distance



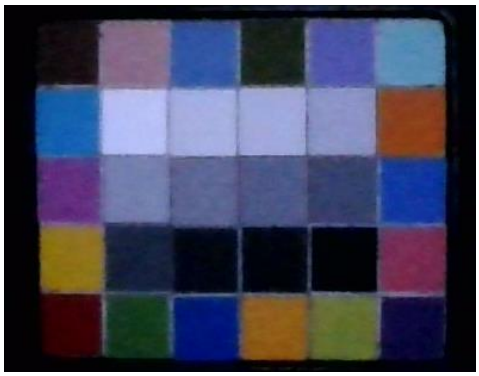


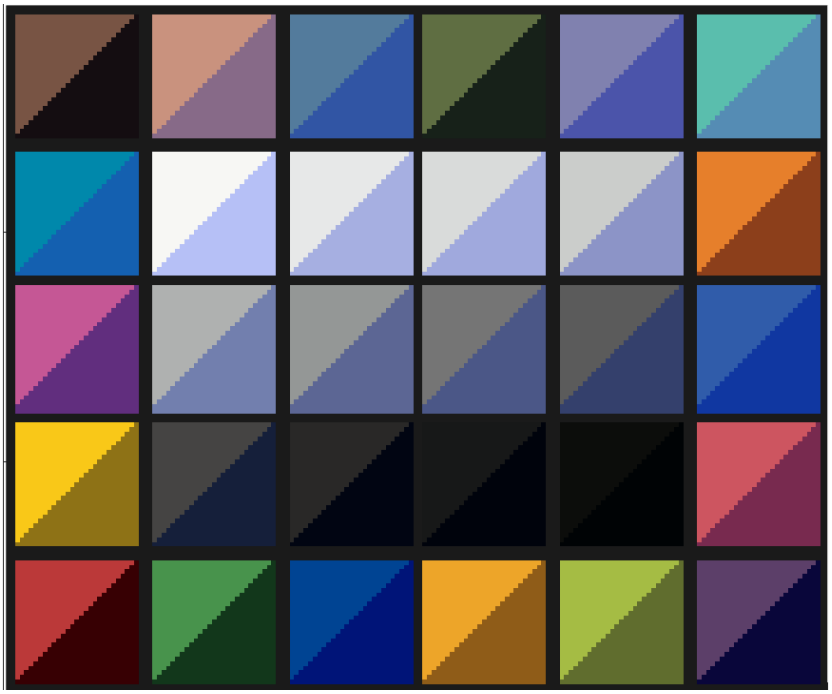
Color Metric	Mean Value
ΔE^*_{ab}	43.8
ΔE_{00}	29.2
ΔC^*_{ab}	28.2
ΔC_{00}	15.0



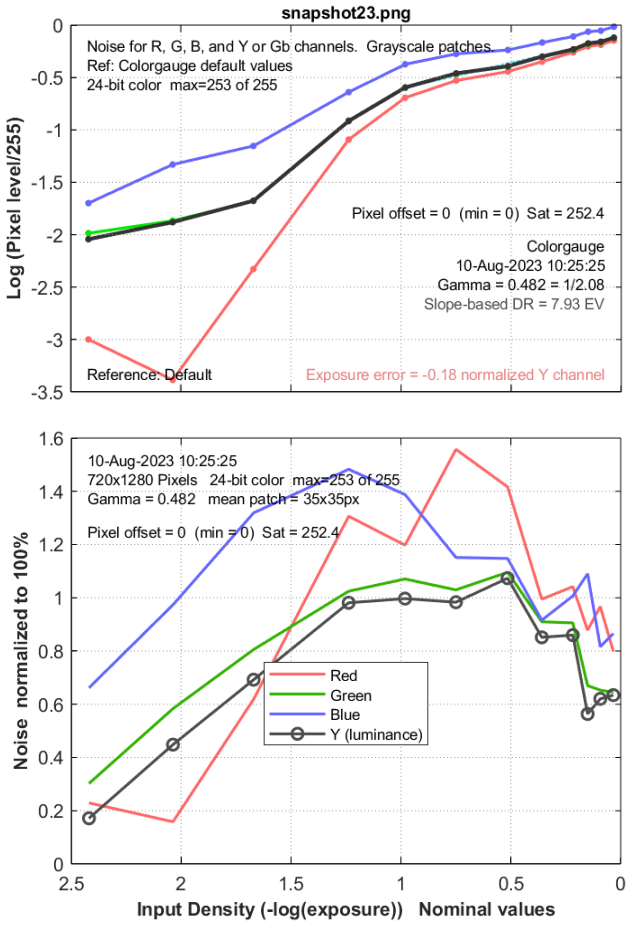


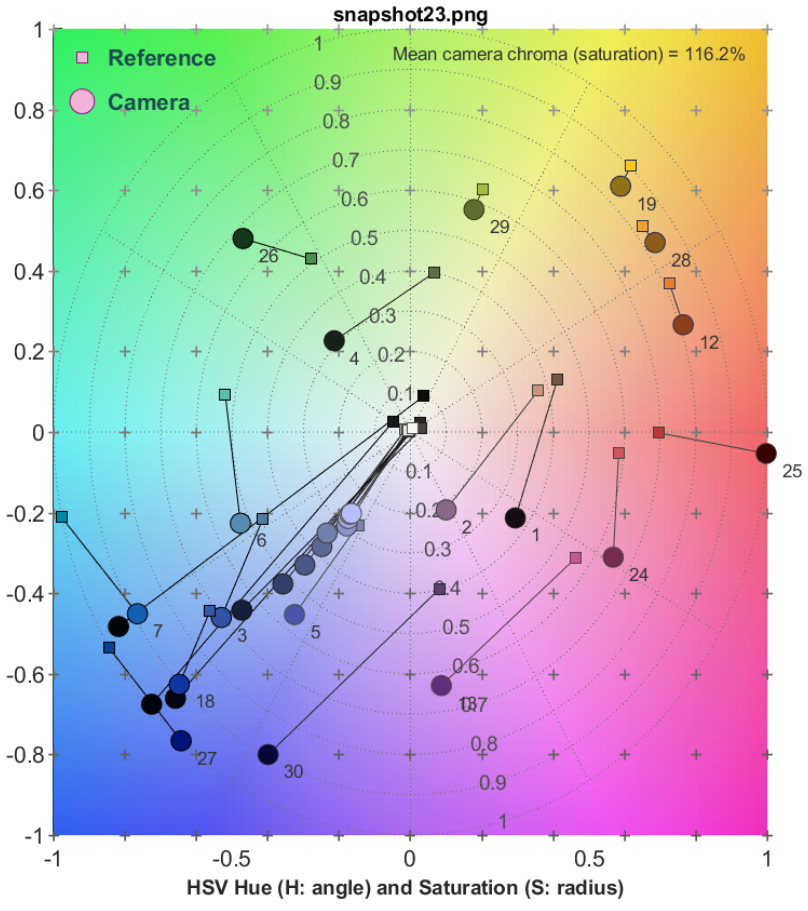
Illumination 2: Saturation Adjusted (5.7 Lux) @ 50mm Distance





Color Metric	Mean Value
ΔE^*_{ab}	32.7
ΔE_{00}	21.6
ΔC^*_{ab}	24.6
ΔC_{00}	12.8





Uniformity

Image nonuniformity can be caused by the lens, the sensor, and the lighting. Nonuniformities may include lens shading, light falloff, or vignetting. These appear in images as visible darkening near the edges of the image, due to the radial nature of the lens which collects more light in the center. It can be particularly strong with wide angle lenses. The captured flatfield image from the DUT is shown in Figure 7.

Figure 7

The luminance contour plot in Figure 8 shows normalized pixel level contours for the image file luminance channel, where luminance is defined as 0.2125*R + 0.7154*G + 0.0721*B. A maximum value of 1 corresponds to the maximum pixel level for a particular bit depth. Illumination nonuniformity is evident in the plot: the top is brighter than the bottom, and the left side and corners are slightly darker. The side and corner regions are shown as red rectangles. The approximate location of the maximum luminance is indicated by a yellow O.

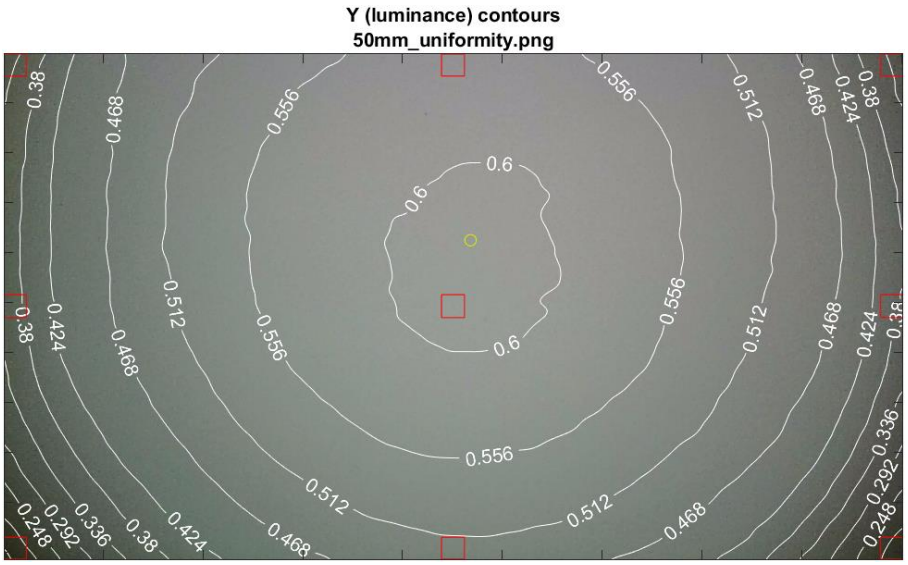


Figure 8

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Distortion

Lens (optical) distortion is an aberration that causes straight lines to curve near the edges of images. The simplest approximation is the 3rd order equation, $r_u = r_d + kr_d^3$ where r_d is the distorted radius and r_u is the undistorted radius. Depending on the sign of k, it can be either "barrel" (which occurs in the captured image in Figure 9) or "pincushion." The 3rd order, 5th order and tangent/arctangent distortion model coefficients are calculated for the captured image. The lens geometric distortion contours and corresponding radial distortion plot are shown in Figures 10 and 11, respectively. The depicted negative distortion quantifies the slight barrel distortion. Also determined are the convergence angles, which are the result of perspective distortion, when the camera is not pointed directly at the target or is misaligned.

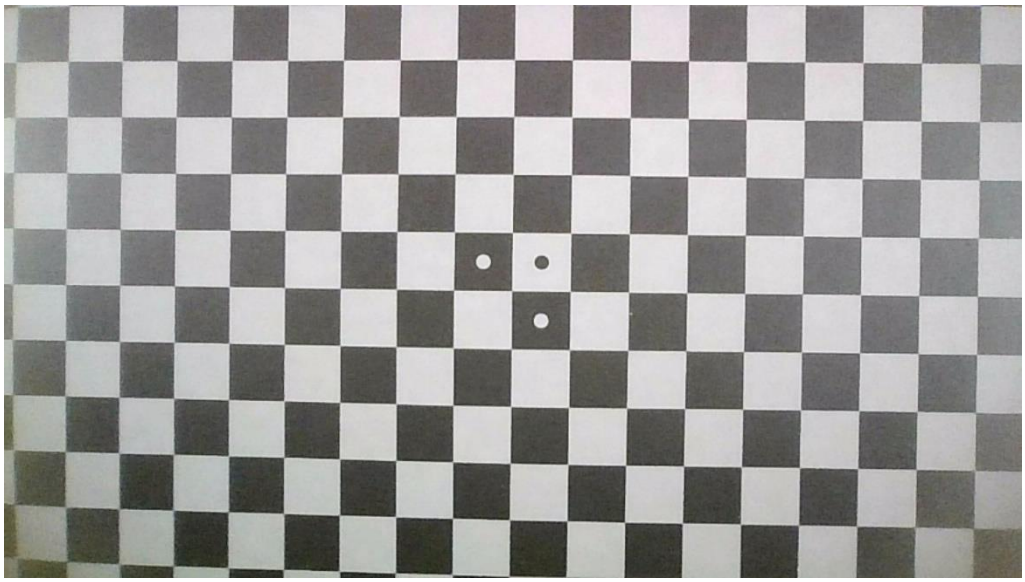

Figure 9

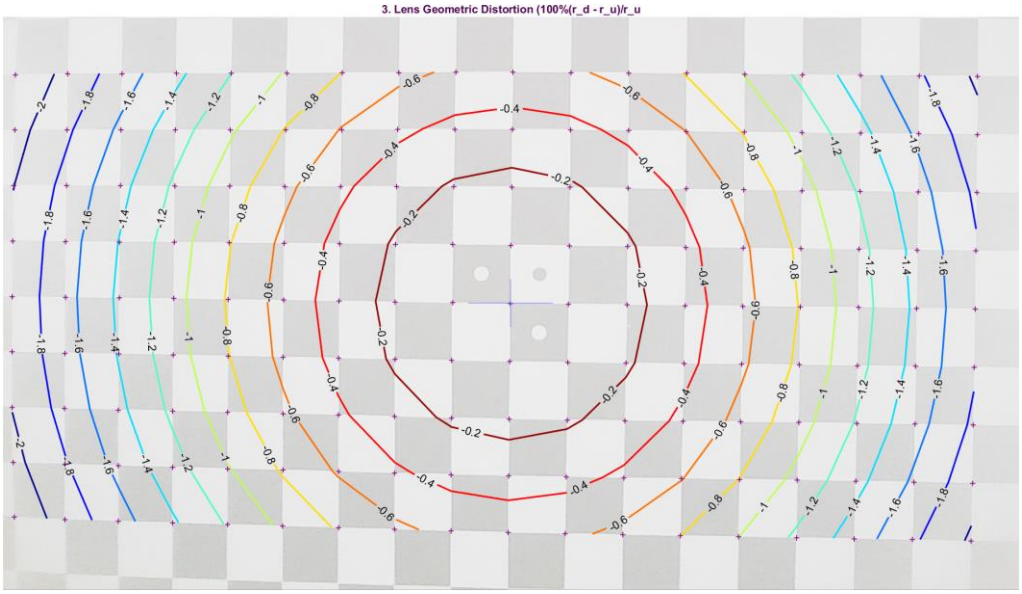

Figure 10

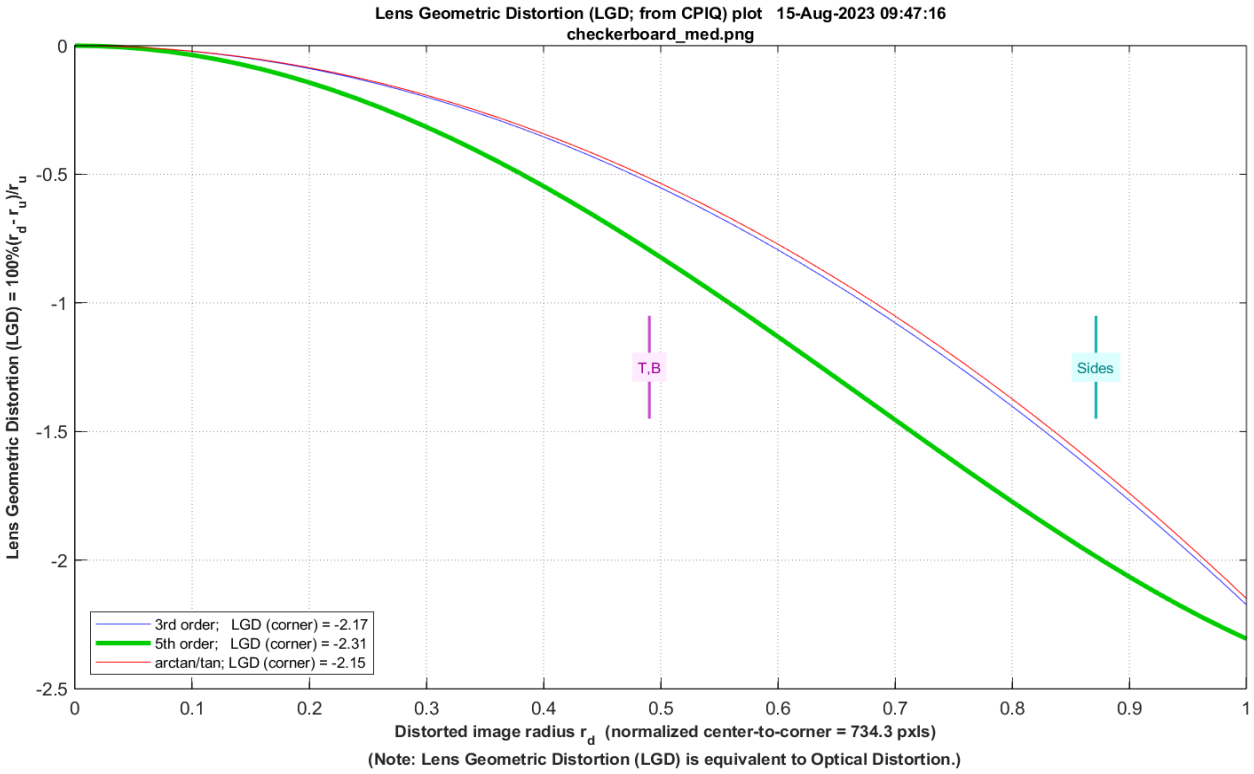

Figure 11

Distortion Metric	Mean Value
3rd Order	$k_1 = 0.022$
5th Order	[0.036, -0.013]
Atan/tan	0.025
Convergence Angles	H: 10.8°; V: -3.67°