Verification of Long-Range MTF Testing Through Intermediary Optics

Alexander Schwartz Sarthak Tandon Jackson Knappen

Imatest LLC - Boulder, CO

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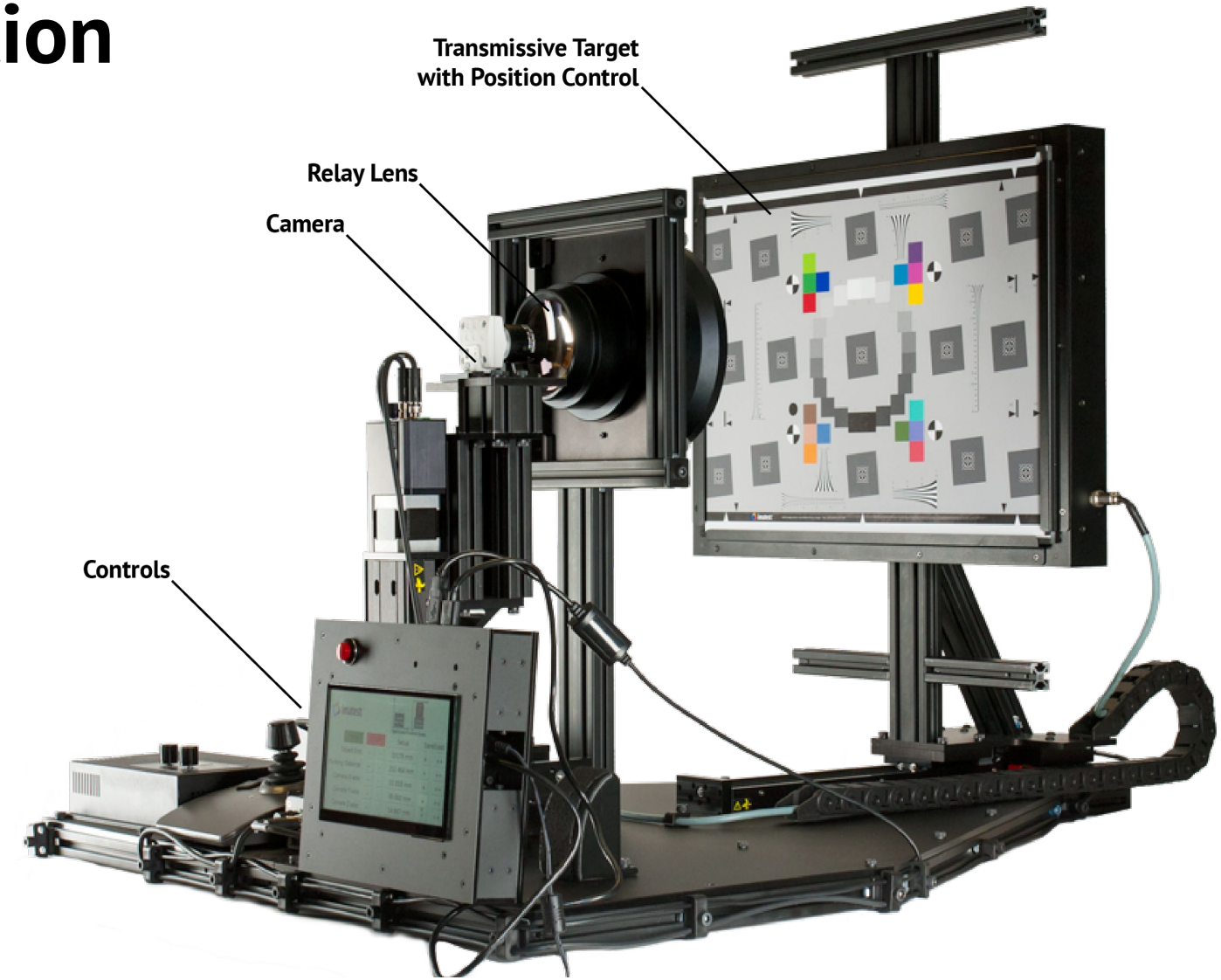
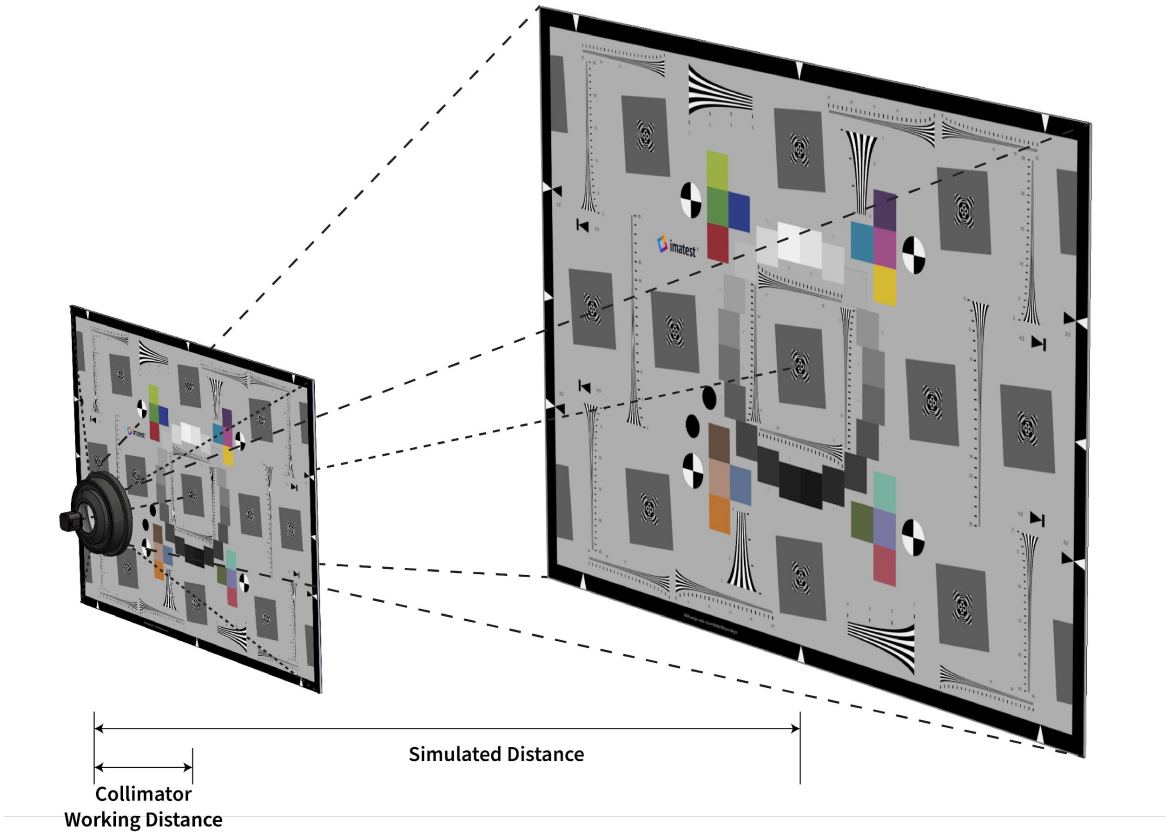
Contents

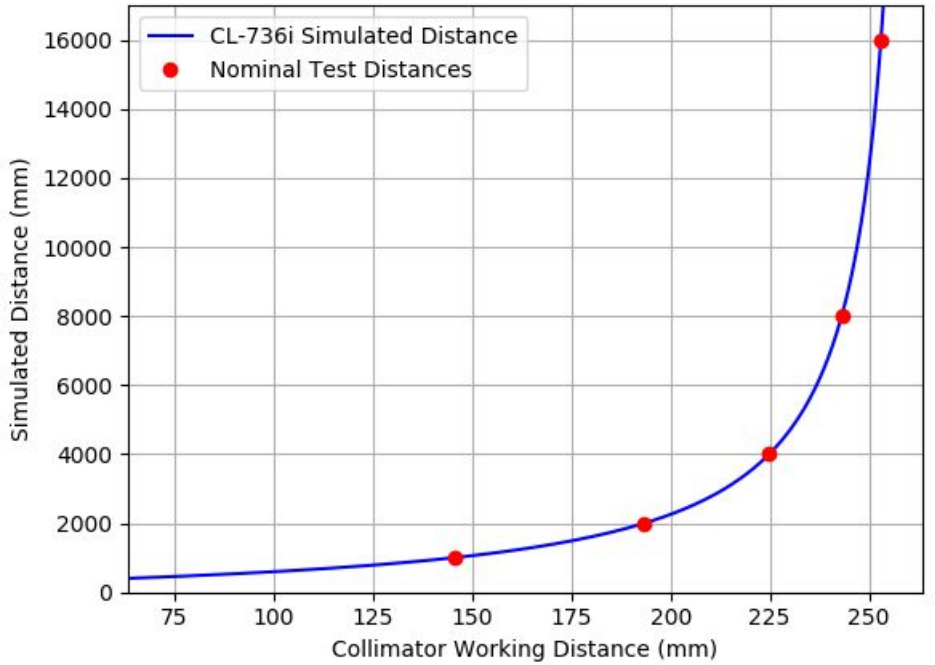
Introduction



Imatest Collimator Fixture

Collimator Working Distance vs Simulated Distance



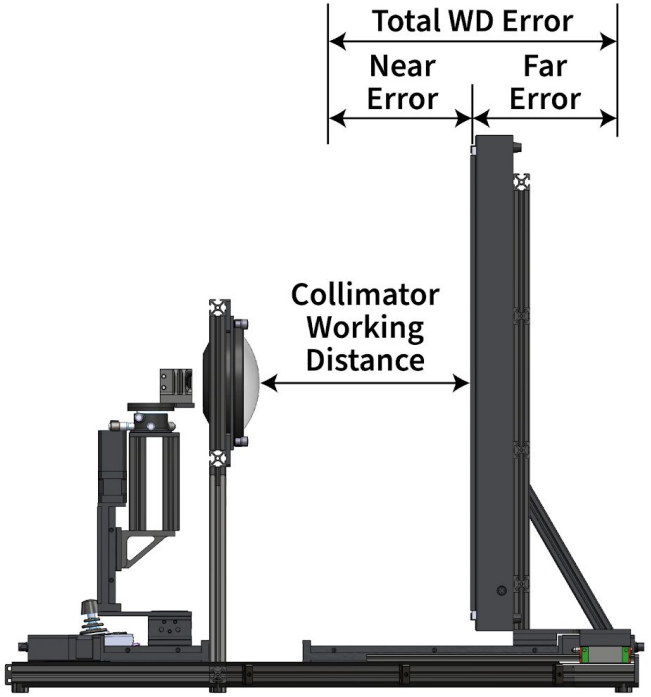


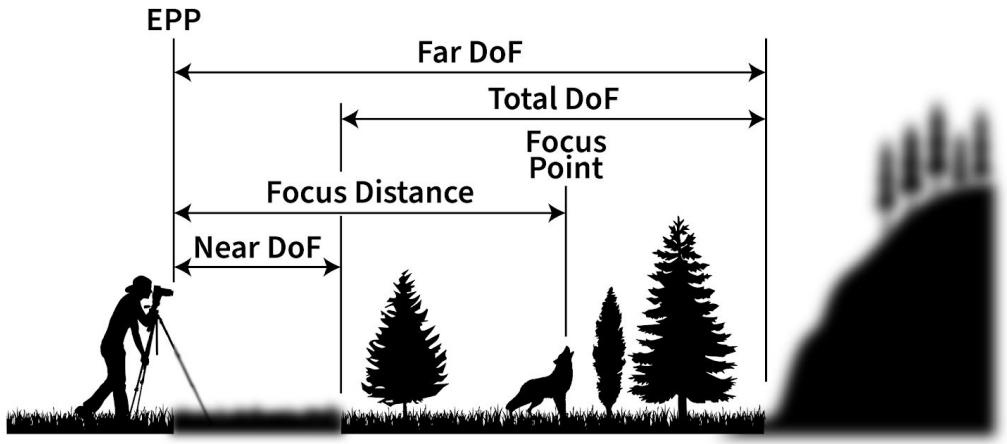
$$SD(WD_C) = \frac{-EFL \cdot (WD_C + H1)}{WD_C + H1 - EFL} - H2 \qquad (1)$$

$$WD_C(SD) = \frac{(-1 \cdot SD - H2) \cdot EFL}{-1 \cdot SD - H2 - EFL} - H1 \qquad (2)$$

Formulas provided by relay lens manufacturer. **[1]**

Maximum Allowable Working Distance Error





$$\mathrm{H} \approx \frac{f^2}{N \cdot C} \tag{3}$$

$$D_{\mathrm{Total}} \approx D_N - D_F \approx \frac{X_0 \cdot H}{H + (X_0 - f)} - \frac{X_0 \cdot H}{H - (X_0 - f)} \tag{4}$$

Hyperfocal Distance and Depth of Field Equations. **[2]**

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Maximum Allowable Working Distance Error

- DUT: f = 28.5mm, N = f/2.8, pixel pitch = 1.67µm. **[3] [4]**
- Circle of Confusion: $C = 2 \cdot 1.67\mu m = 0.00334mm$
- *Allowed WD_C Error*:
  - Difference between WD_C at the *nominal focus distance* and WD_C at both the *Near and Far DoF*.
- *Total DoF* increases at longer focus distances up until *H* (hyperfocal distance).
- ***Allowed WD_C Error* increases at longer distances because it is dependent on the *DoF* of the imaging system in use.**

$$WD_C(SD) = \frac{(-1 \cdot SD - H2) \cdot EFL}{-1 \cdot SD - H2 - EFL} - H1 \qquad (2)$$

Estimated DoF for EO Camera + 35mm lens, f/2.8

Nominal Focus Distance	D_N	D_F	Total *DoF*	Allowed WD_C $Error_N$	Allowed WD_C $Error_F$
[m]	[m]	[m]	[m]	[mm]	[mm]
1.0	0.9889	1.0113	0.0224	0.900	0.906
2.0	1.9556	2.0465	0.0908	1.286	1.297
4.0	3.8251	4.1917	0.3666	1.577	1.592
8.0	7.3275	8.8085	1.4810	1.759	1.776
16.0	13.5148	19.6052	6.0905	1.862	1.881

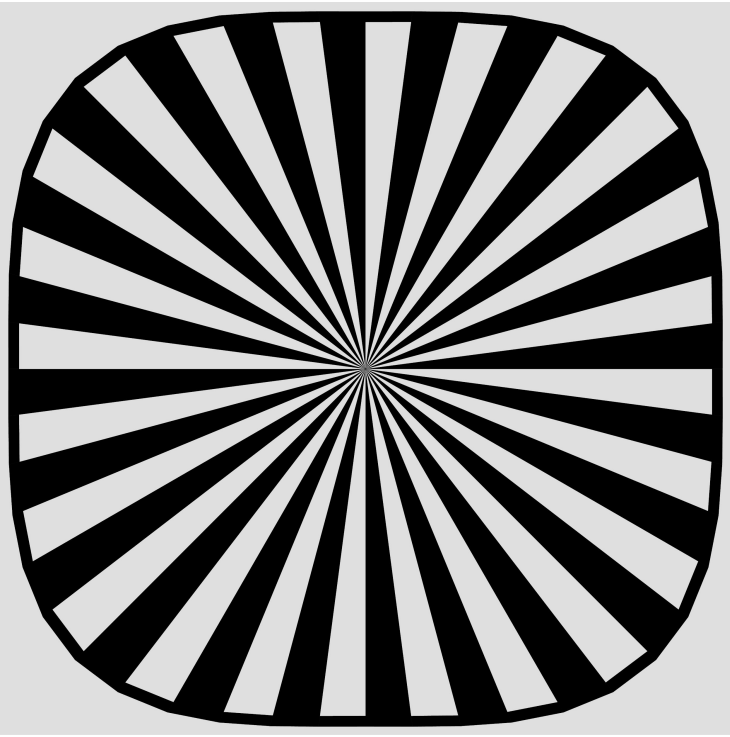
$$\mathrm{H} \approx \frac{f^2}{N \cdot C} \qquad (3)$$

$$D_{\mathrm{Total}} \approx D_N - D_F \approx \frac{X_0 \cdot H}{H + (X_0 - f)} - \frac{X_0 \cdot H}{H - (X_0 - f)} \qquad (4)$$

Simulated Distance Verification Methodology

- A machine vision camera with a lockable focus lens is used to verify specific nominal test distances.
- A laser rangefinder (Bosch GLM500) is used to measure distances.
- Nominal distances: **1m, 2m, 4m, 8m,** and **16m**.
- For each test distance, the procedure for capturing real world images is followed directly by capturing images at simulated distances through the intermediary optic.
- A focus star (**43.5” x43.5”**) is used to visually determine the *Peak Focus Distance* before capturing images.

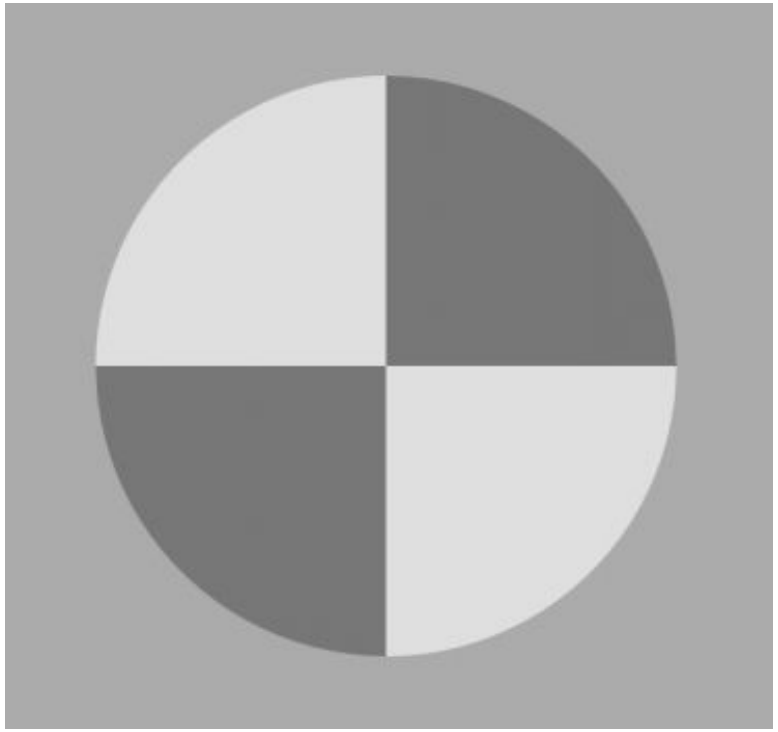
Modular Test Stand
Chart Holder & Camera Rail **[5]**



Focus Star Pattern (Inkjet, 43.5” x43.5”)

Simulated Distance Verification Methodology

- Large SFRreg Target (**40” x 40”**) used for Real World Captures.
- Three images are captured at the *Peak Focus Distance*.
- Additional images are captured with incremental WD_C *Error* above and below the *Peak Focus Distance*:
  - WD_C is derived from *Equation 2,* where *SD* is set to the *Peak Focus Distance*.
  - Additional incremental real world distances derived from *Equation 1* with the following WD_C intervals:
    - Derived nominal WD_C **±0.5mm**, **±1.0mm**, **±1.5mm**, **±2mm**, **±2.5mm**, **±3mm**, and **±3.5mm**



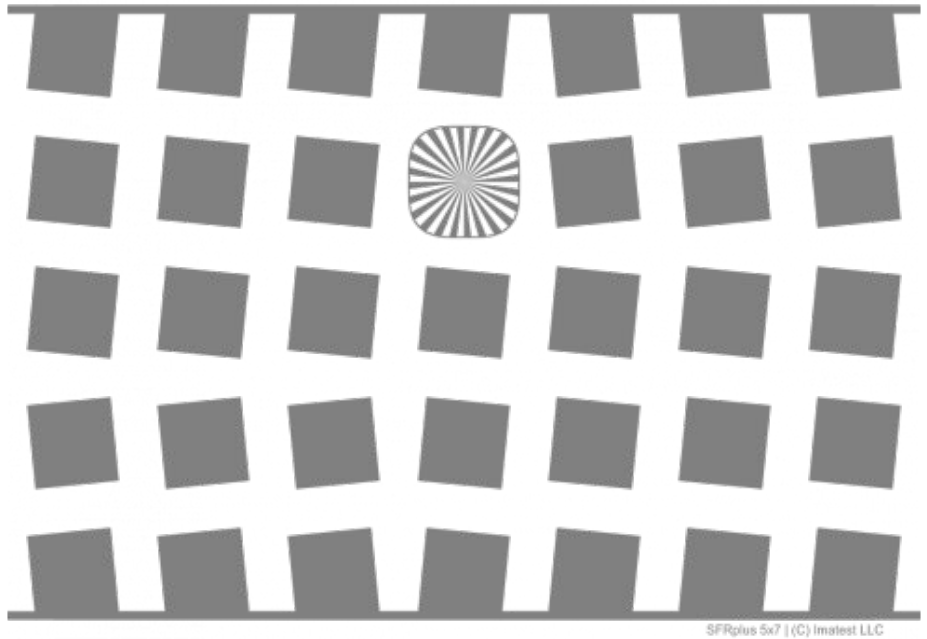
SFRreg Pattern (Inkjet, 40” x 40”)

$$SD(WD_C) = \frac{-EFL \cdot (WD_C + H1)}{WD_C + H1 - EFL} - H2 \qquad (1)$$

$$WD_C(SD) = \frac{(-1 \cdot SD - H2) \cdot EFL}{-1 \cdot SD - H2 - EFL} - H1 \qquad (2)$$

Simulated Distance Verification Methodology

- The camera is mounted to the collimator fixture with the EPP centered about the exit pupil of the CL736i lens.
- Three images are captured at the simulated *Peak Focus Distance* and each additional incremental distance.
- For real world measurements, record the weighted mean MTF frequency at 50% modulus, or *MTF50* from all four slanted edges of the SFRreg target using the SFRreg Auto module.
- MTF compensation **[6]** is used for calculating *MTF50* from 1m, 2m, and 4m real world captures.
- For collimator fixture measurements, record the weighted mean *MTF50* for all slanted edges of the Chrome on Glass SFRplus target using the SFRplus Auto module.



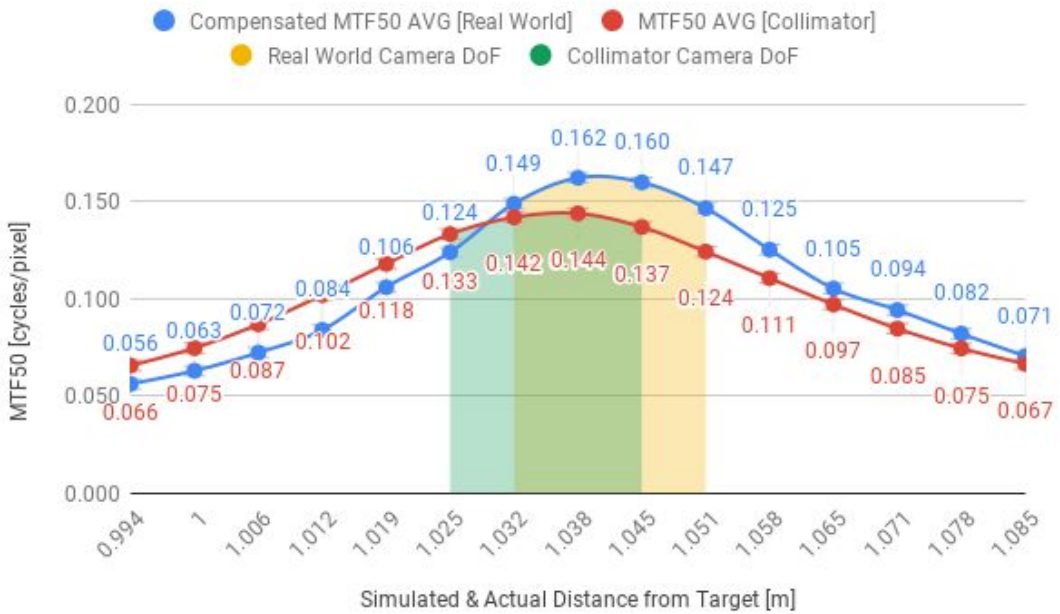
SFRplus Pattern (Chrome on Glass, 2″ x 2″) **[7]**

Results

WD_C Validation Result Summary

Nominal Focus Distance	Actual Real World Peak Focus	Actual Collimator Peak Focus	DoF Overlap
[m]	[m]	[m]	[m]
1.0	1.038	1.038	0.022
2.0	2.006	2.015	0.050
4.0	4.028	3.970	0.290
8.0	8.022	7.818	1.020
16.0	15.285	15.645	4.600

MTF50 VS Simulated/Actual Distance (1m Nominal)



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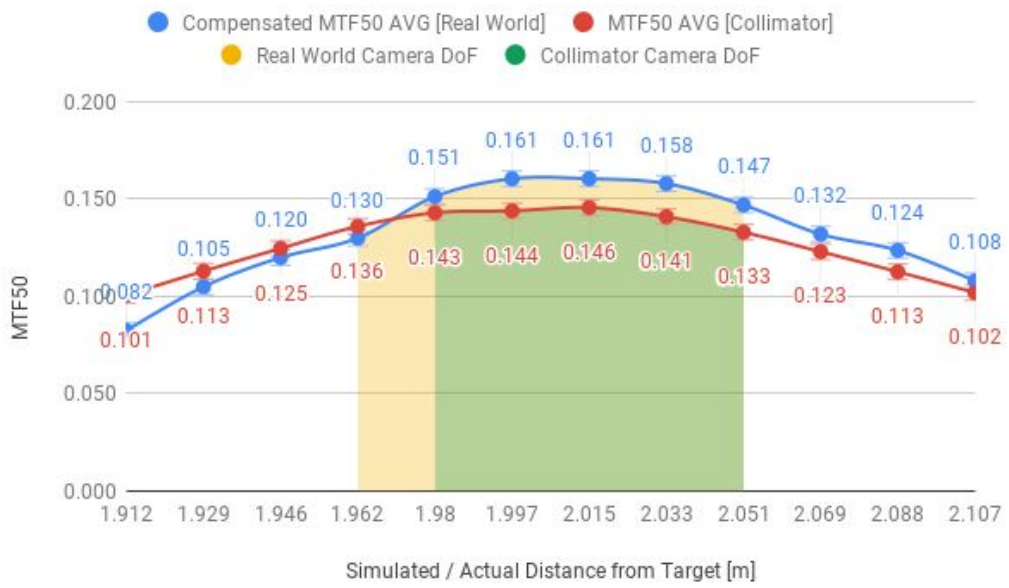
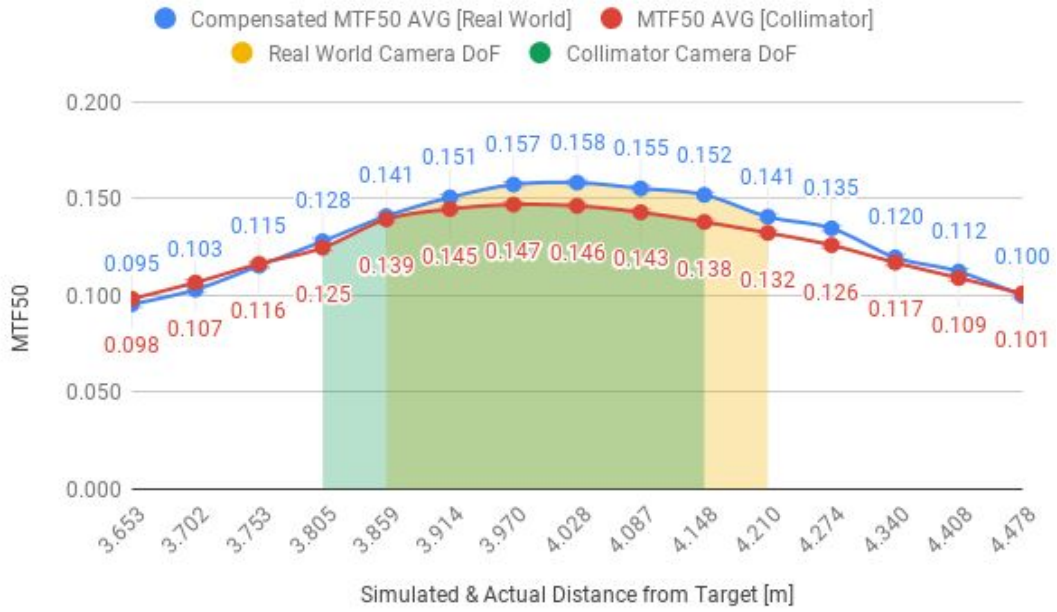
Results

MTF50 VS Simulated/Actual Distance (2m Nominal)

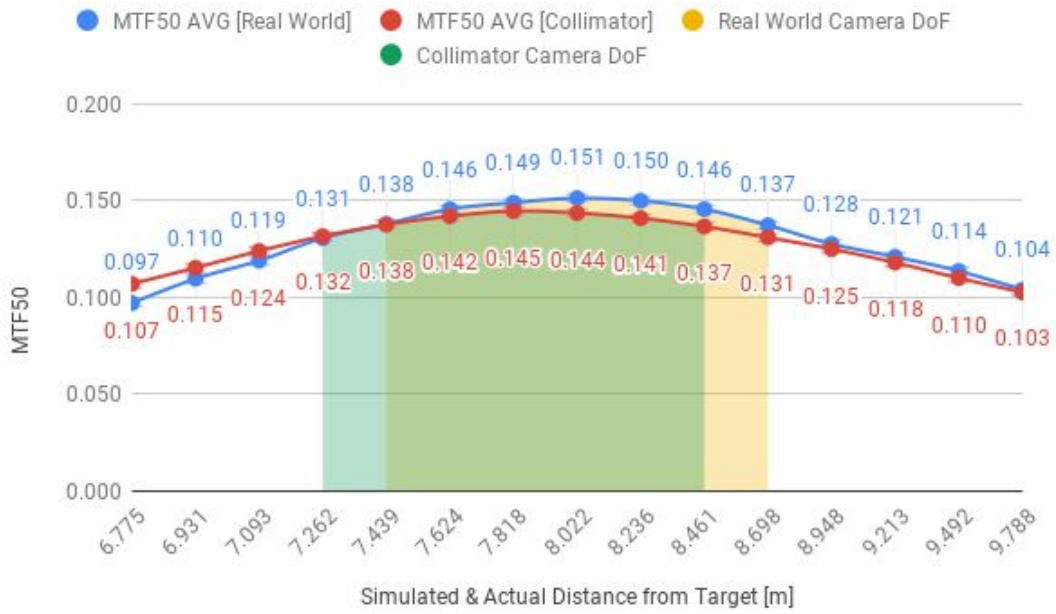


MTF50 VS Simulated/Actual Distance (4m Nominal)

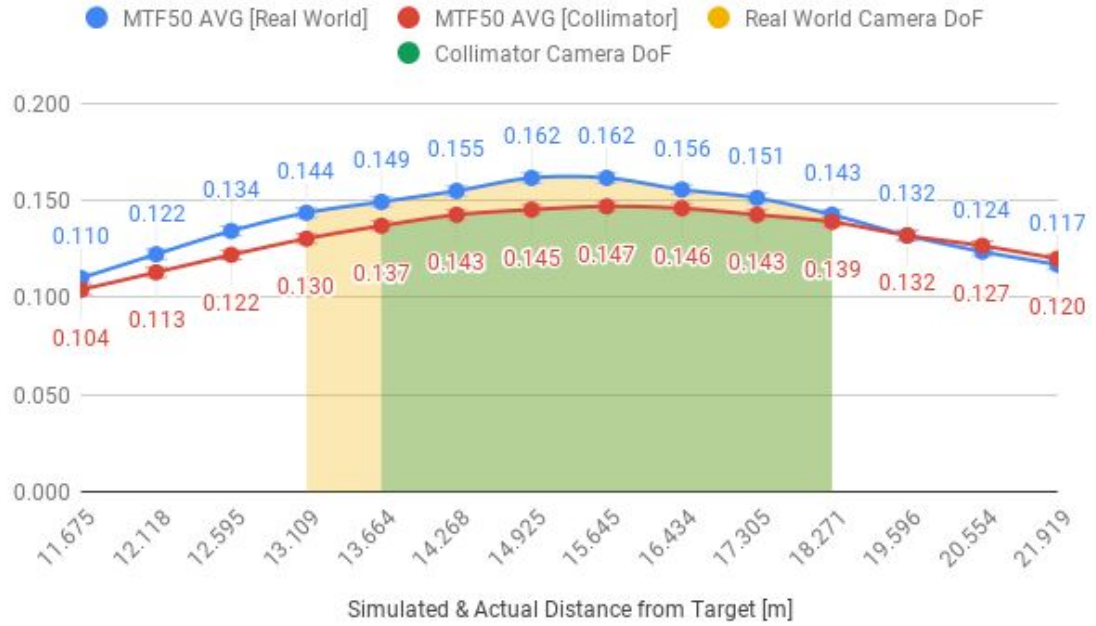


Results

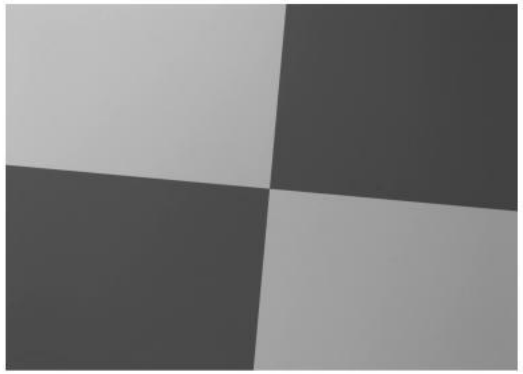
MTF50 VS Simulated/Actual Distance (8m Nominal)

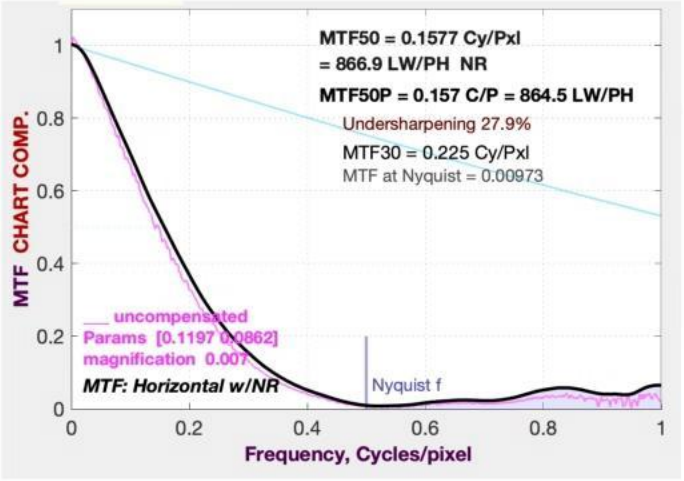


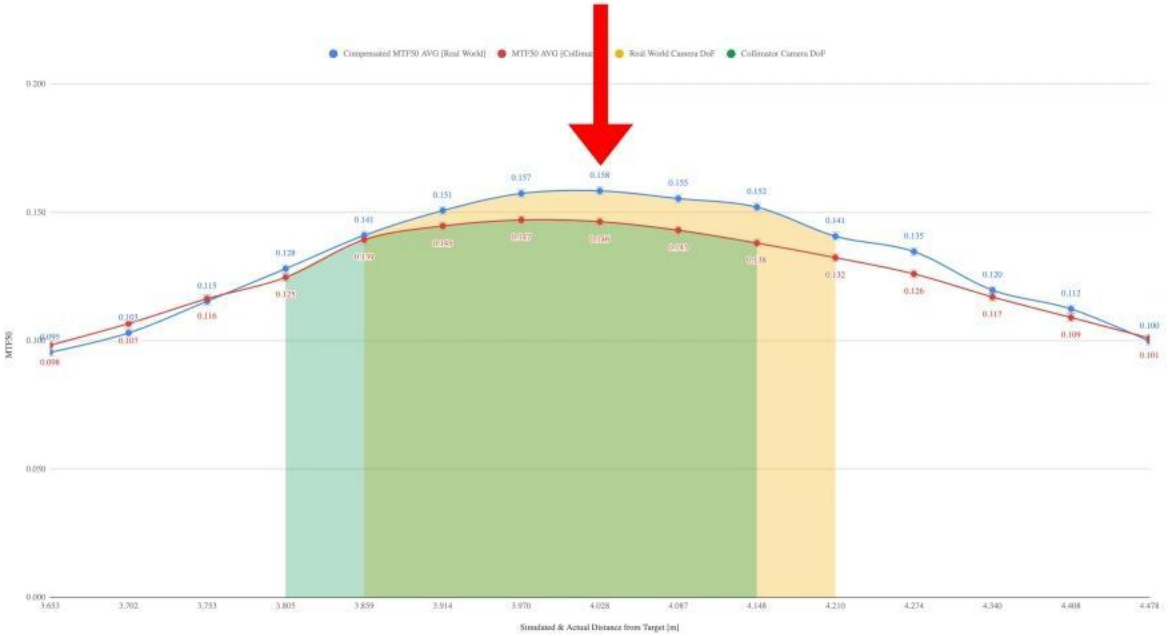
MTF50 VS Simulated/Actual Distance (16m Nominal)



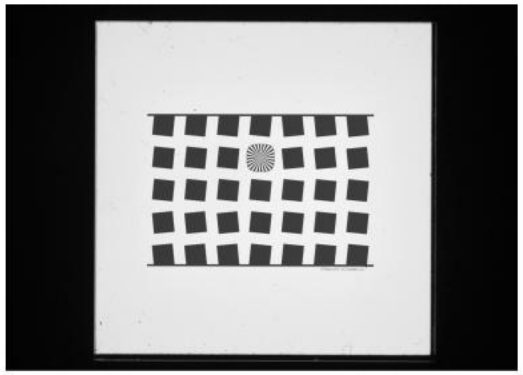
Real World Captures (4m)

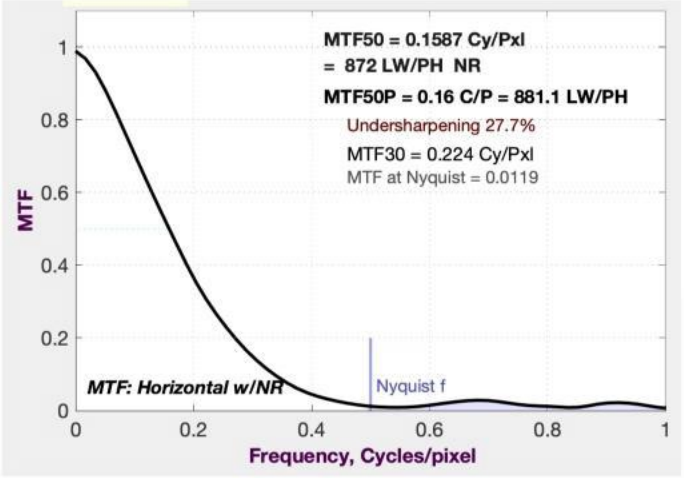






Virtual Distance Captures (4m)





Conclusions

- The Imatest Collimator Fixture passes simulated distance verification at each nominal focus distance (**1m, 2m, 4m, 8m,** and **16m**).
- At **1m, 2m, 4m, 8m**, the Collimator projects images closer than the intended *SD*: WD_C *Error-Near* **≤ 0.5mm**.
- At **16m**, the Collimator projects images farther than the intended *SD*: WD_C *Error-Far* **≈ 0.25mm**.
- These discrepancies can be attributed to an imperfect relay lens model, optical defects, experimental error, and/or inaccurate calibration.
- Testing with this method, the CL-736i relay lens decreases peak *MTF50* by an average of **8.4%**.
- Some MTF loss is expected when adding intermediary optics to the system.
- Results with this magnitude of MTF loss still provides meaningful imaging system measurements.
- Once the MTF loss is understood, it can be compensated for using golden or bronze sample testing. **[8]**

Limitations & Future Work

- The tests performed sample a small portion of the total FOV of the relay lens
- Off axis testing will provide information on relay lens performance at the edges of the imaging plane
- Simulated distance verification was performed to a maximum distance of 20 meters
- A giant test target (Billboard sized SFRreg target) is needed for extreme long range free space testing

References

[1] Simulated distance equations provided by OneStone - Lens Design & Manufacture.

[2] Greenleaf, Allen R., Photographic Optics, The MacMillan Company, New York, 1950, pp. 25-27

[3] “EO-10012C ½" CMOS Color USB Lite Edition Camera | Edmund Optics." https://www.edmundoptics.com/p/eo-10012ccmos-color-usb-lite-edition-camera-/22782/. Accessed 29 Jul. 2019.

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[5] "Compensating camera MTF measurements for chart and ...." http://www.imatest.com/docs/mtf-compensation/. Accessed 22 Nov. 2019.

[6] "Imatest Modular Test Stand - Imatest Lab Setup - Equipment." http://store.imatest.com/equipment/imatest-lab-setup/imatest-modular-test-stand.html. Accessed 29 Jul. 2019.

[7] "SFRplus Target on Chrome on Glass - More Transmissive Sharpness ...." http://store.imatest.com/test-charts/resolution-charts/trans-charts/sfrplus-chart-chrome-on-glass.html. Accessed 29 Jul. 2019.

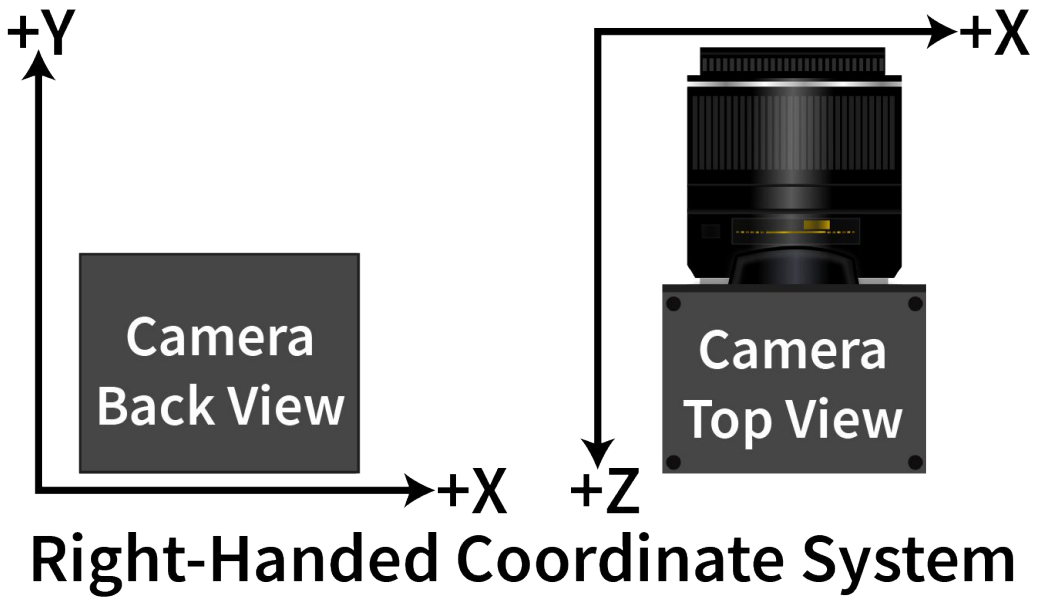
[8] "Understanding collimator MTF loss using bronze and golden sample ...." 9 May. 2019, http://www.imatest.com/2019/05/understanding-collimator-mtf-loss-using-bronze-and-golden-sample-testing/. Accessed 29 Jul. 2019.

Thank you to my co-authors and the Imatest team.

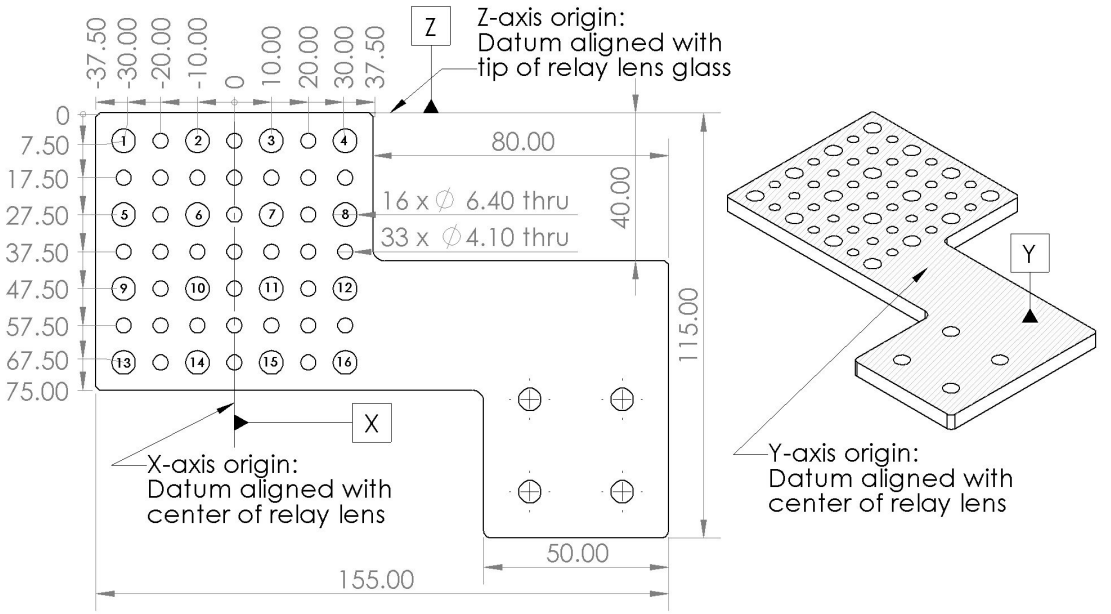
Thank you for your attention.

Questions?

Coordinate System and Camera Mounting Datums

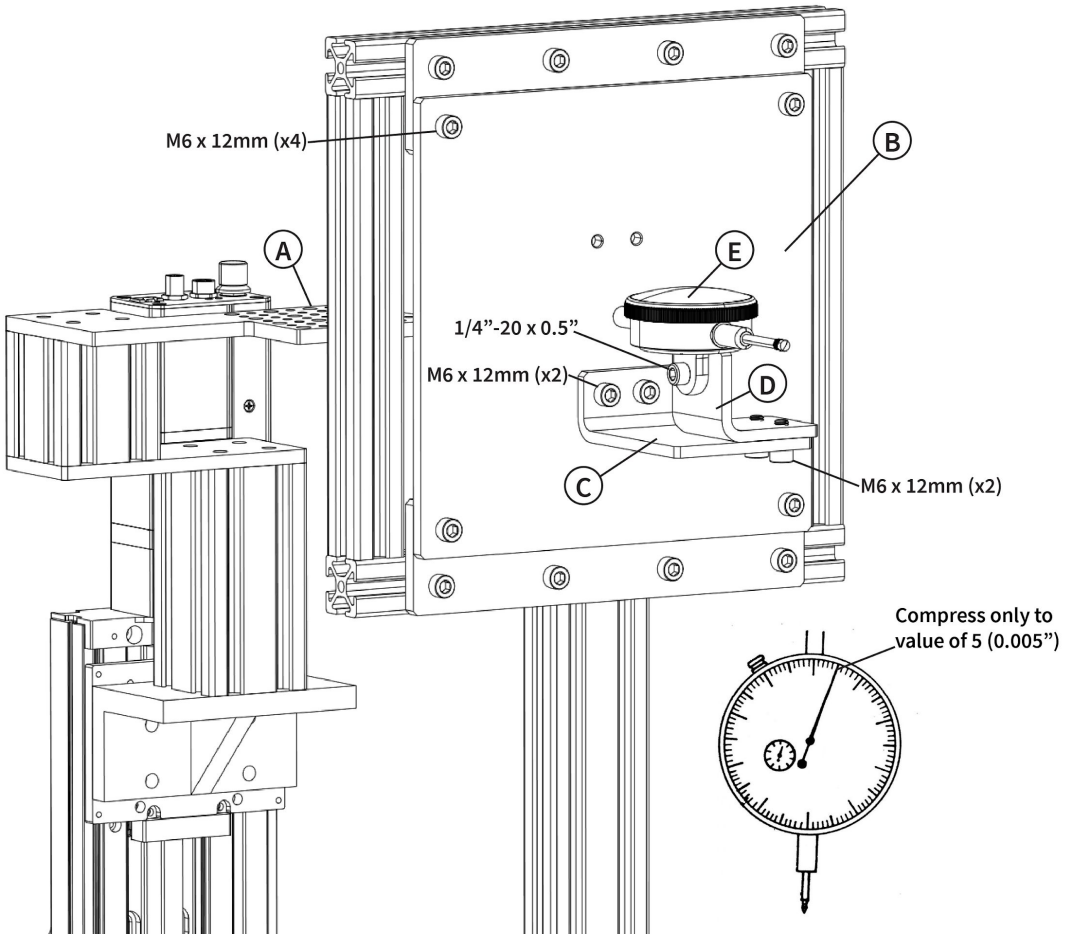


Collimator Fixture Coordinate System

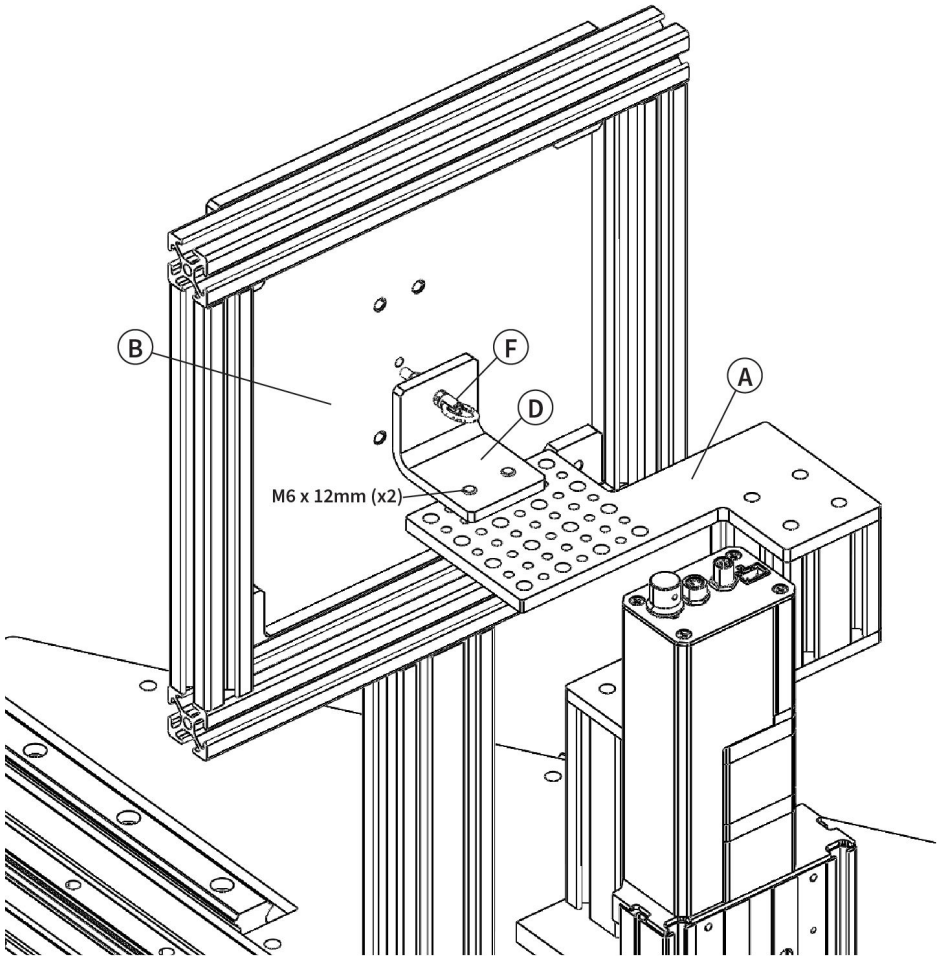


Top Camera Mounting Plate Diagram (Part A)

Calibration



Configuration for Working Distance Calibration



Configuration for Camera X & Y axis Calibration