Calibration overview

December 3, 2020

AHEAD OF WHAT'S POSSIBLE™

Calibration charts deliverables

- Focus Target
  - Focus target needs to be assembled by LGIT in Korea
  - Imatest SFRPlus chart (35.5”x35.5”) will arrive in Korea around Wed 9th December (tracking details TBC)
  - Backing panel for focus chart (36”x36”) will arrive in Korea around Wed 9th December (tracking details TBC)
  - LGIT need to glue the chart to the panel (need to source adhesive locally, for example this one on Amazon)
  - LGIT should unroll the focus chart and lay it flat with some weights on top to keep it flat for at least 24 hours before mounting on the backing panel
- Geometric Target
  - Geometric target will be fully assembled in US before shipping to Korea
  - Estimated delivery of target to Korea is Wed 16th December (better estimate available next week)
  - Station can be configured with focus target in advance to check illumination and mechanical structure
- Question
  - Are there any mechanical constraints we should be aware of regarding how the target is mounted in the development pipeline at LGIT?

Calibration software PC requirements

- System Requirements
  - Windows 10 PC with USB 3.1 Gen 2 support
- Minimal Host PC settings
  - Seventh Gen Intel® CoreTM i5 Processor (Dual Core 2.4 GHz)
  - 8 GB Memory Intel HD620 GPU or faster
  - Graphics driver with support for OpenCL 2.0 (or higher)
- Recommended Host PC Settings
  - Ninth Generation Intel(R) Core(TM) i7-9850H CPU @ 2.60GHz, 2592 Mhz, 6 Core(s), 12 Logical Processor(s)
  - 16 GB Memory Intel(R) UHD 630 Graphics Card
  - Graphics driver with support for OpenCL 2.0 (or higher)
- Software Requirements
  - Visual C++ Redistributable
  - OpenCL support
- Software Prerequisites
  - Anaconda or Miniconda
  - Imatest

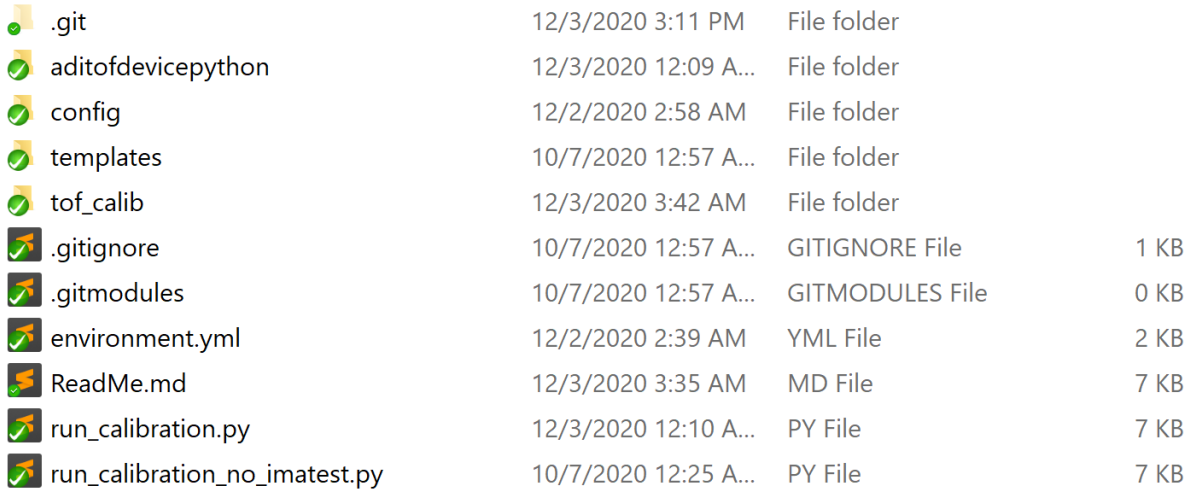
Imatest software license options

License option	Comment	Options
Imatest IT	This is the only license required to run the ADI calibration pipeline. It provides the python interface to the Imatest software	Node locked license
		Floating license
Imatest Master	This license is only required if changes need to be made to the Imatest setting. It enables an Imatest Engineering GUI	Node locked license
		Floating license
Imatest Ultimate (IT + Master)	This is a combination of the other 2 licenses.	Node locked license
		Floating license

- ADI engineering pipeline requires Imatest IT (or Ultimate) license to run Blemish and Focus calibration
- The Engineering GUI in Imatest Master is only required if changes need to be made such as:
  - Modifying Imatest setup for a different focus chart configuration.
  - Modifying output results/images returned by the Imatest software
- A floating license is convenient for bring-up when stations aren't running in parallel and multiple different laptops are used by different Engineers
- Each station using Imatest features would likely require an individual node-locked IT license in production

Software delivery package

Delivery date: Friday Dec 4, 2020



.git	12/3/2020 3:11 PM	File folder	
aditofdevicepython	12/3/2020 12:09 A...	File folder	
config	12/2/2020 2:58 AM	File folder	
templates	10/7/2020 12:57 A...	File folder	
tof_calib	12/3/2020 3:42 AM	File folder	
.gitignore	10/7/2020 12:57 A...	GITIGNORE File	1 KB
.gitmodules	10/7/2020 12:57 A...	GITMODULES File	0 KB
environment.yml	12/2/2020 2:39 AM	YML File	2 KB
ReadMe.md	12/3/2020 3:35 AM	MD File	7 KB
run_calibration.py	12/3/2020 12:10 A...	PY File	7 KB
run_calibration_no_imatest.py	10/7/2020 12:25 A...	PY File	7 KB

├── /tof_calib: functions for calibration

├── /aditofdevicepython: SDK python bindings

├── /config: configuration files

├── /templates: calibration report templates

├── environment.yml: yml file to create an anaconda environment

├── run_calibration.py: script to start a calibration session

└── run_calibration_no_imatest.py: script to start a limited calibration session if Imatest is not installed

Calibration software steps

- Starting a calibration session
  - python run_calibration.py <path-to-yaml_config_file> <OPTIONAL session_dir_name>
- This opens the calibration menu where calibrations are listed in the recommended order
- The status of the calibration is listed on the right
- The desired calibration can be performed by entering the option code (ex: 1,2,Q or q)

```
Loaded Imatest IT Python Library 2020.1.7

============================
    ToF Calibration v0.5.0
============================

Calibration file directory created-> Walden001
Configuration file used -> ./config/CalibrationConfig_Walden.yaml

OPTIONS:
1 -> CONNECTIVITY TEST and ICQ     :NOT EXEC
2 -> GAIN AND OFFSET CALIBRATION   :NOT EXEC
3 -> VLOW AND DAC TRIM             :NOT EXEC
4 -> BLEMISH TEST                  :NOT EXEC
5 -> FOCUS ADJUSTMENT              :NOT EXEC
6 -> FOCUS VERIFICATION            :NOT EXEC
7 -> GEOMETRIC CALIBRATION         :NOT EXEC
8 -> LSDAC SETTING *               :NOT EXEC
9 -> P0 CALIBRATION                :NOT EXEC
R -> GENERATE REPORT
C -> WRITE TO CCB
Q -> QUIT

* manual entry

Select option:Q
```

Calibration software steps

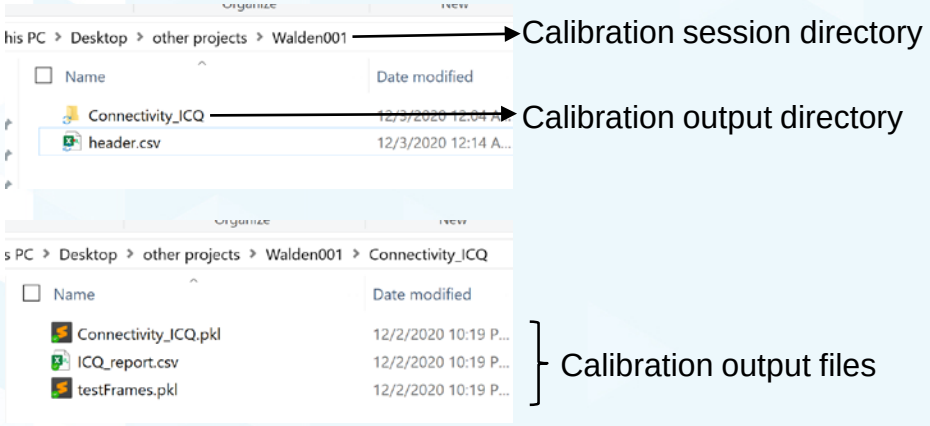
- After a calibration is performed, the script returns to the menu.
- If the calibration is successful, the status of that calibration changes to 'PASS'
- If the calibration is unsuccessful or if it encounters an error or is interrupted, the status changes to 'INCOMPLETE'
- A calibration directory is generated in the session directory and the output files are stored

```
============================
    ToF Calibration v0.5.0
============================

Calibration file directory created-> Walden001
Configuration file used -> ./config/CalibrationConfig_WaldenArcher.yaml

OPTIONS:
1 -> CONNECTIVITY TEST and ICQ     :PASS
2 -> GAIN AND OFFSET CALIBRATION   :NOT EXEC
3 -> VLOW AND DAC TRIM             :NOT EXEC
```

Option 1 is completed successfully

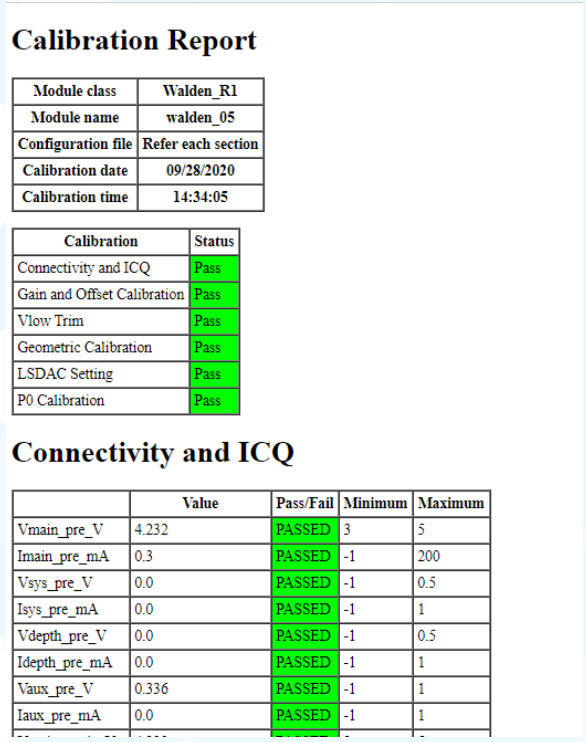
```
============================
    ToF Calibration v0.5.0
============================

Calibration file directory created-> Walden001
Configuration file used -> ./config/CalibrationConfig_WaldenArcher.yaml

OPTIONS:
1 -> CONNECTIVITY TEST and ICQ     :INCOMPLETE
2 -> GAIN AND OFFSET CALIBRATION   :NOT EXEC
3 -> VLOW AND DAC TRIM             :NOT EXEC
```

Option 1 is not completed successfully



Calibration software steps

- To generate a .ccb calibration file, select the option 'C' or 'c'
- Only calibrations completed successfully are added to the .ccb file
- To generate a html report on the calibration performed, select the option 'R' or 'r'



Calibration Report

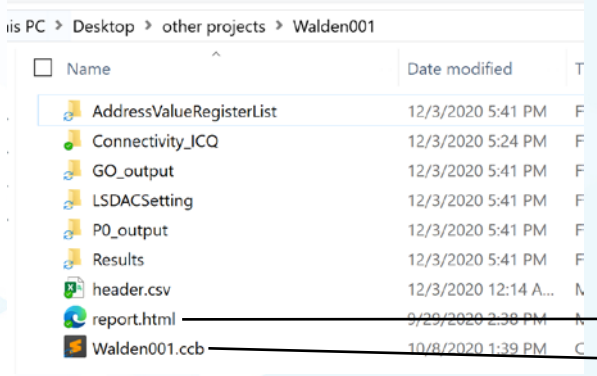
Module class	Walden_R1
Module name	walden_05
Configuration file	Refer each section
Calibration date	09/28/2020
Calibration time	14:34:05

Calibration	Status
Connectivity and ICQ	Pass
Gain and Offset Calibration	Pass
Vlow Trim	Pass
Geometric Calibration	Pass
LSDAC Setting	Pass
P0 Calibration	Pass

Connectivity and ICQ

	Value	Pass/Fail	Minimum	Maximum
Vmain_pre_V	4.232	PASSED	3	5
Imain_pre_mA	0.3	PASSED	-1	200
Vsys_pre_V	0.0	PASSED	-1	0.5
Isys_pre_mA	0.0	PASSED	-1	1
Vdepth_pre_V	0.0	PASSED	-1	0.5
Idepth_pre_mA	0.0	PASSED	-1	1
Vaux_pre_V	0.336	PASSED	-1	1
Iaux_pre_mA	0.0	PASSED	-1	1

Sample report



Backup

Calibration pipeline & deliverables

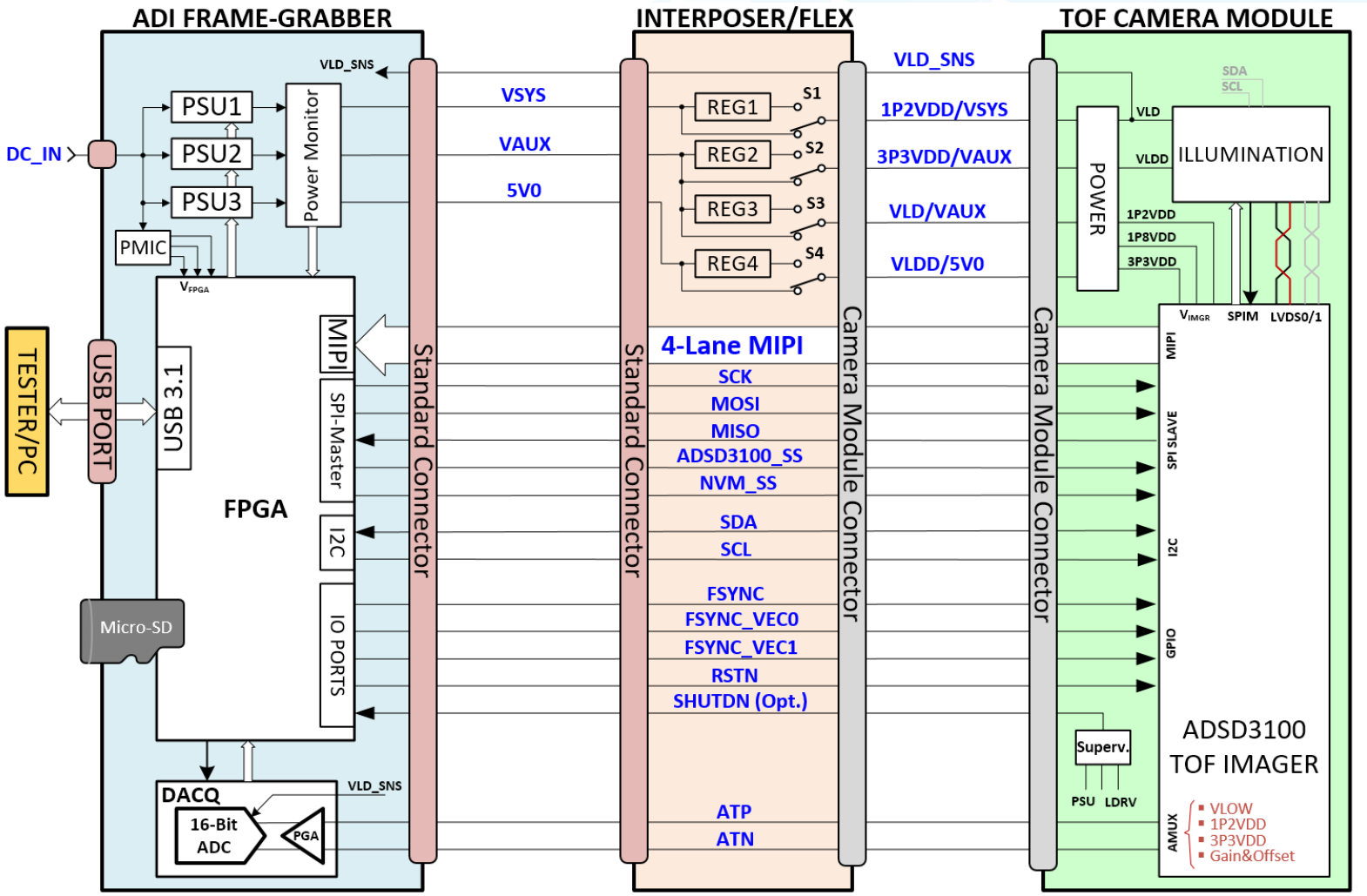
Station	Additional Equipment	Current status	Comments	Delivery date
Electrical verification/ calibration	None	Python script	Incoming quality check, Gain & Offset calibration, VLOW and DAC trim	Source code end-October
Blemish verification	Light panel	3rd party software (Imatest)		Source code end-October (license dependency)
Lens focus adjustment	Focus chart + NIR illumination	3rd party software (Imatest)		Source code end-October (license dependency)
Geometric calibration	Checkerboard target + NIR illumination	Python script + OpenCV	Proprietary ADI target construction	Source code end-October
Optical power calibration	Integrating sphere + power meter + controller board	LabView script (trigger power meter from FG)	Conversion to Python in progress	Source code end-November
P0 calibration	Enclosure + mirror + diffuser over lens	Python script		Source code end-October
Final QA check	Scene with targets at known depths	Python script	Verify depth accuracy	Source code end-November

Calibration Pipeline Details & Photos

Camera calibration pipeline

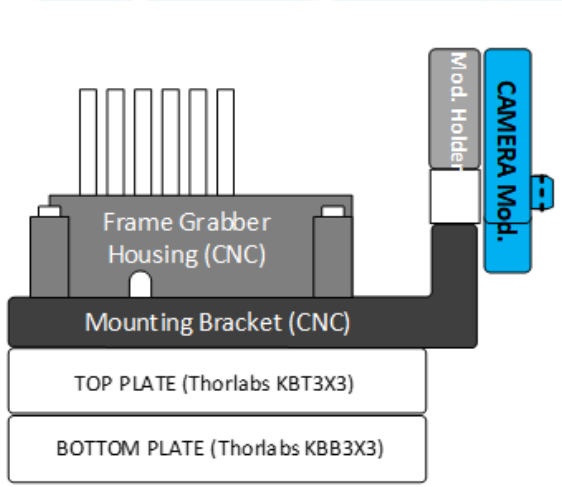
Incoming quality check	• Test supply and internal voltages • Check sensor characteristics such as PLL lock time
Gain/Offset	• VLOW Calibration • Adjust column amplifier and ADC settings • Calibration of column gain and offset mismatch
Lens focus	• Adjust lens focus
Geometric	• Calculate lens intrinsic and distortion coefficients • Generate radial distance to point cloud conversion table
Optical power	• Measure optical power and adjust laser driver settings
P0	• Measure and store absolute phase offset at each pixel • Produce temperature correction model
Illumination profile	• Check light profile variations
Final check	• Verify depth quality metrics using test scene

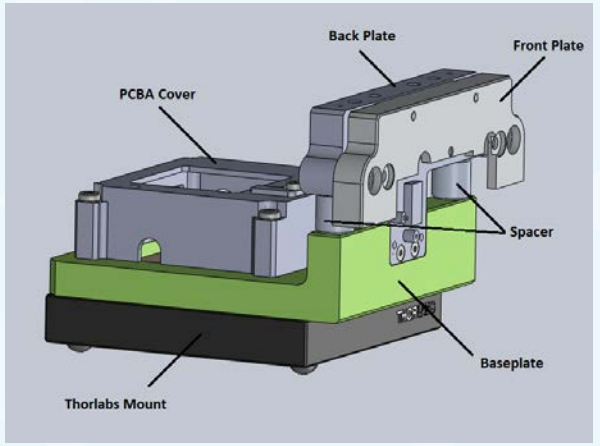
ToF module calibration setup

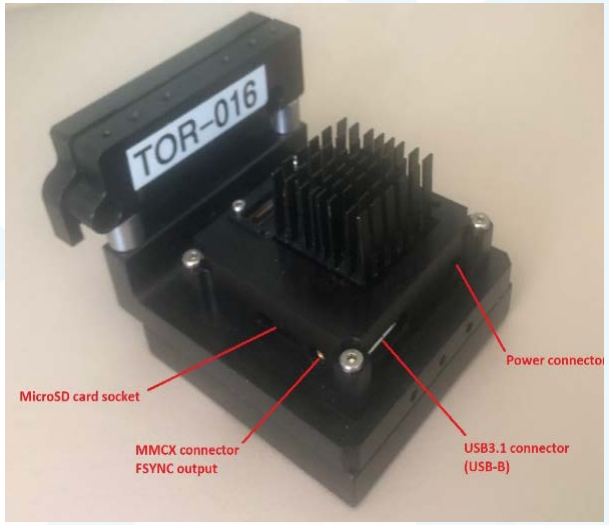


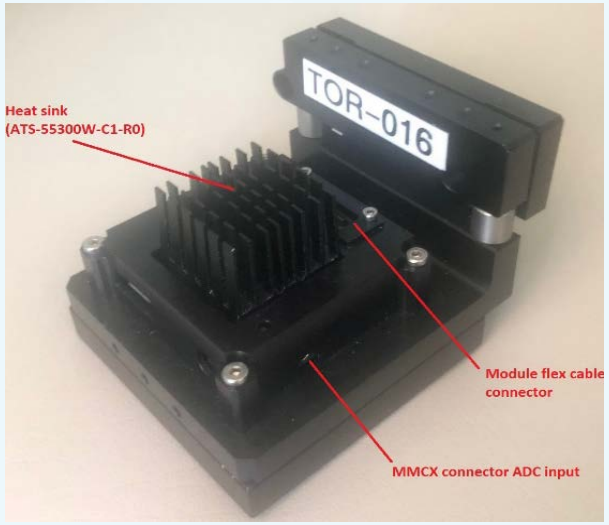
ADI Frame Grabber

- ADI Frame Grabber is a dedicated FPGA-based host platform that connects to the camera module for calibration and module characterization
  - Safely power the module
  - Processes raw MIPI data from the module and transfers images to host PC over USB 3.1
  - Also performs some calibration functions
- Acts as a mechanical mount for the module to ensure repeatable placement and alignment
- Mounted on Thorlabs kinematic mount to enable movement between calibration stations



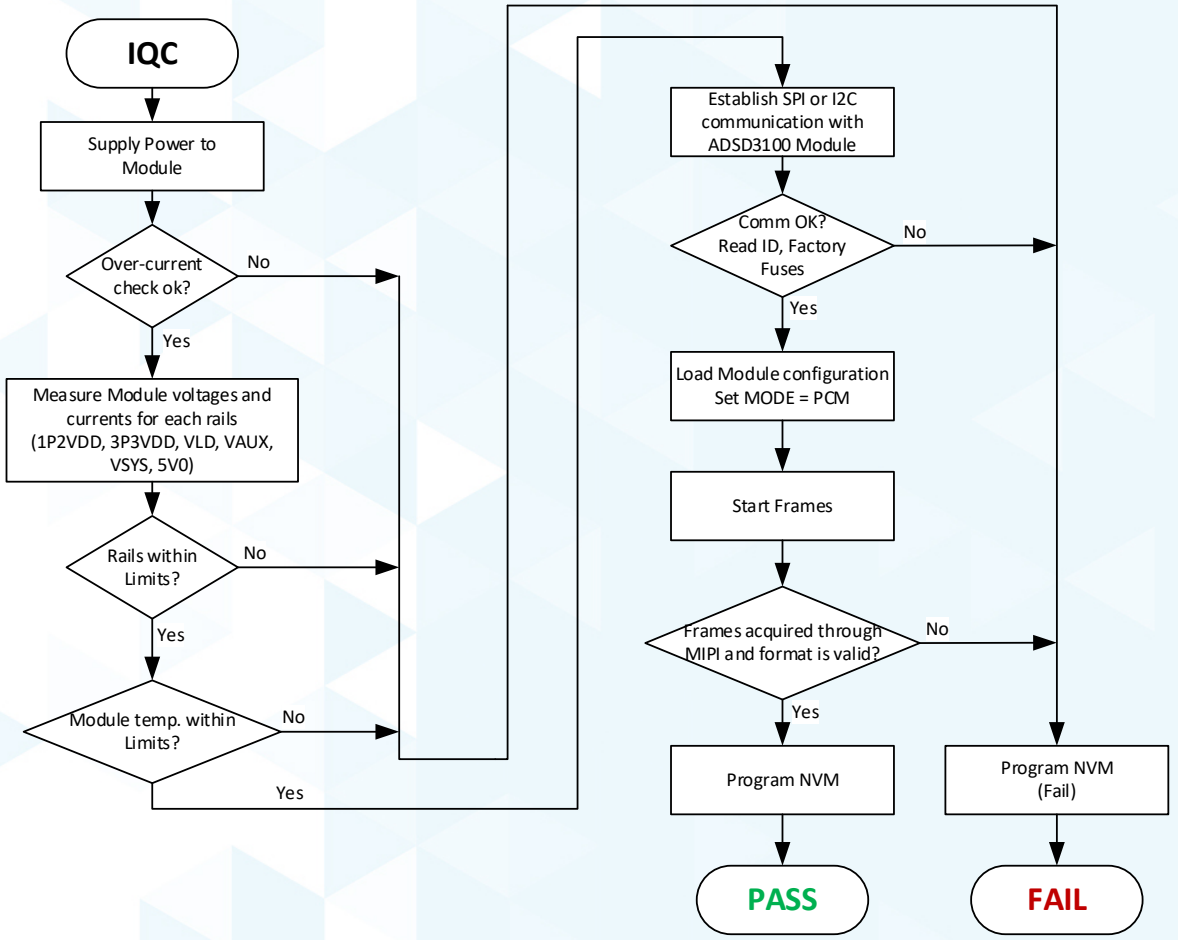






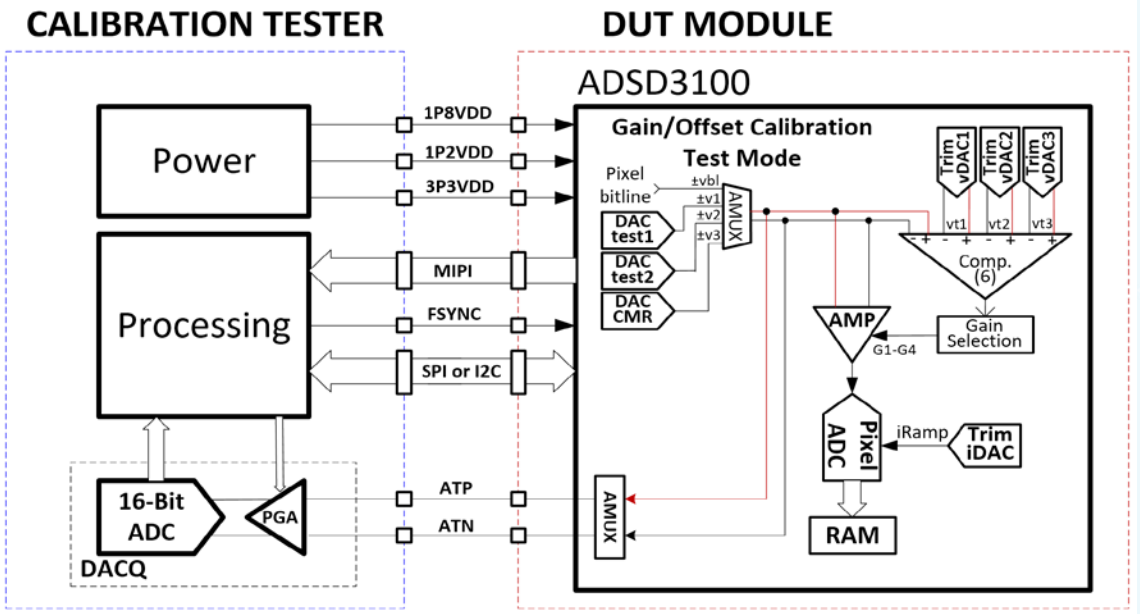
Incoming Quality Check (IQC)

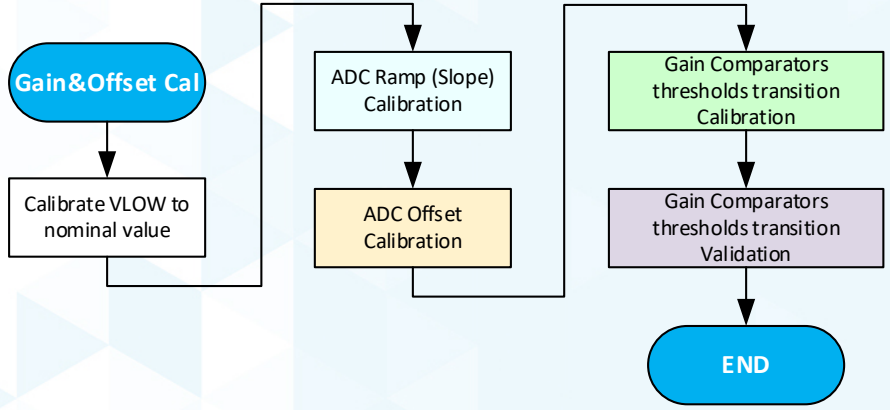
- Purpose
  - Check module is electrically functional before proceeding through the calibration pipeline
- Procedure
  - All tests performed using ADI frame grabber, no dedicated calibration station required
  - Check module power supply voltages and currents are within expected range
  - Check internal signals on ADSD3100 via analog test pins (ATP/ATN)
    - Internal supply rail voltages
    - Internal PLL lock times
  - Verify MIPI streaming is operational by capturing passive IR images



Gain & Offset Calibration

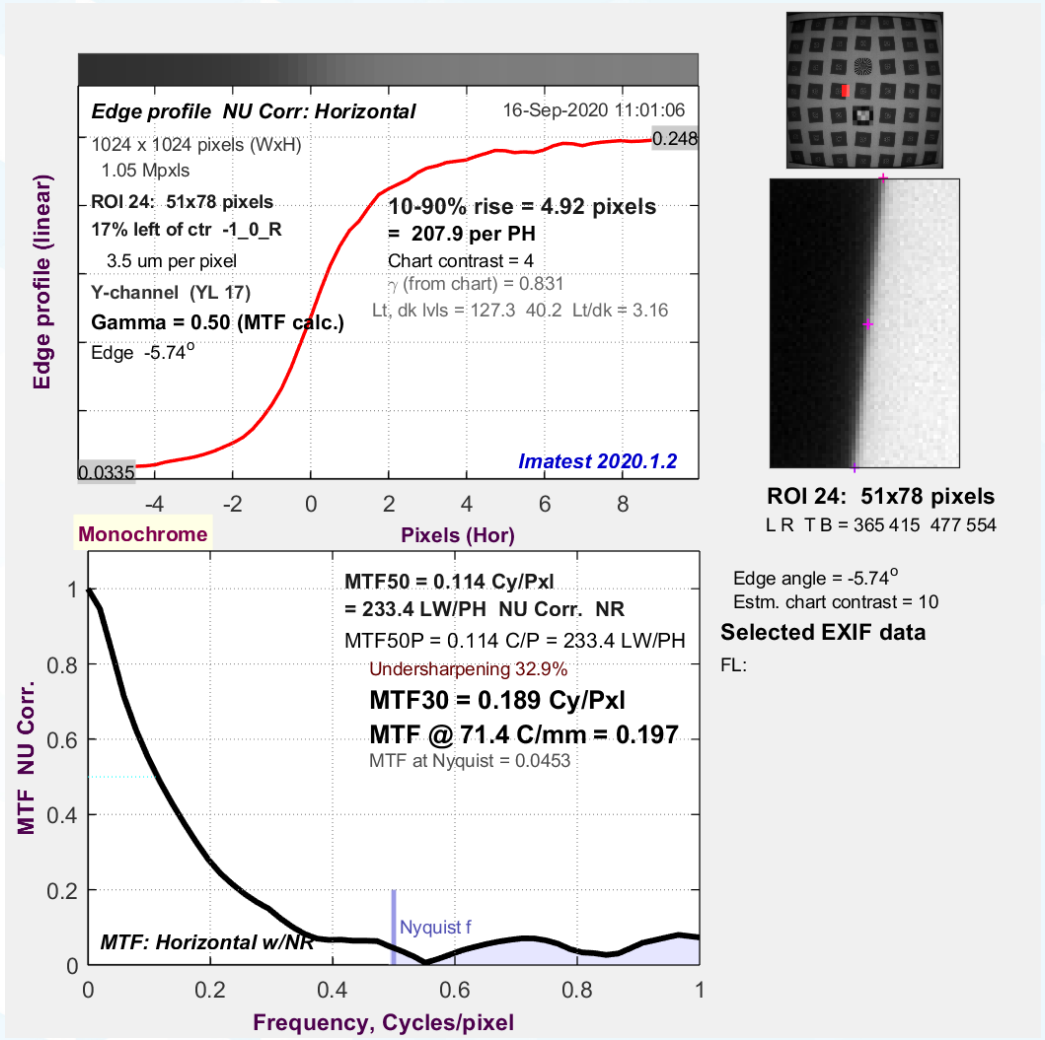
- Purpose
  - Remove column fixed pattern noise
  - Optimize measurement range while avoiding saturation at transition between gain stages
  - Calibrate VLOW sensor supply voltage
- Procedure
  - All tests performed using ADI frame grabber, no dedicated calibration station required
  - VLOW measured via analog test pins
  - ADSD3100 programmed to operate in special mode, pixel bitline replaced by internal DACs
  - ADC slope and offset calibrated
  - Gain comparator thresholds calibrated
  - Calibration results saved to NVM



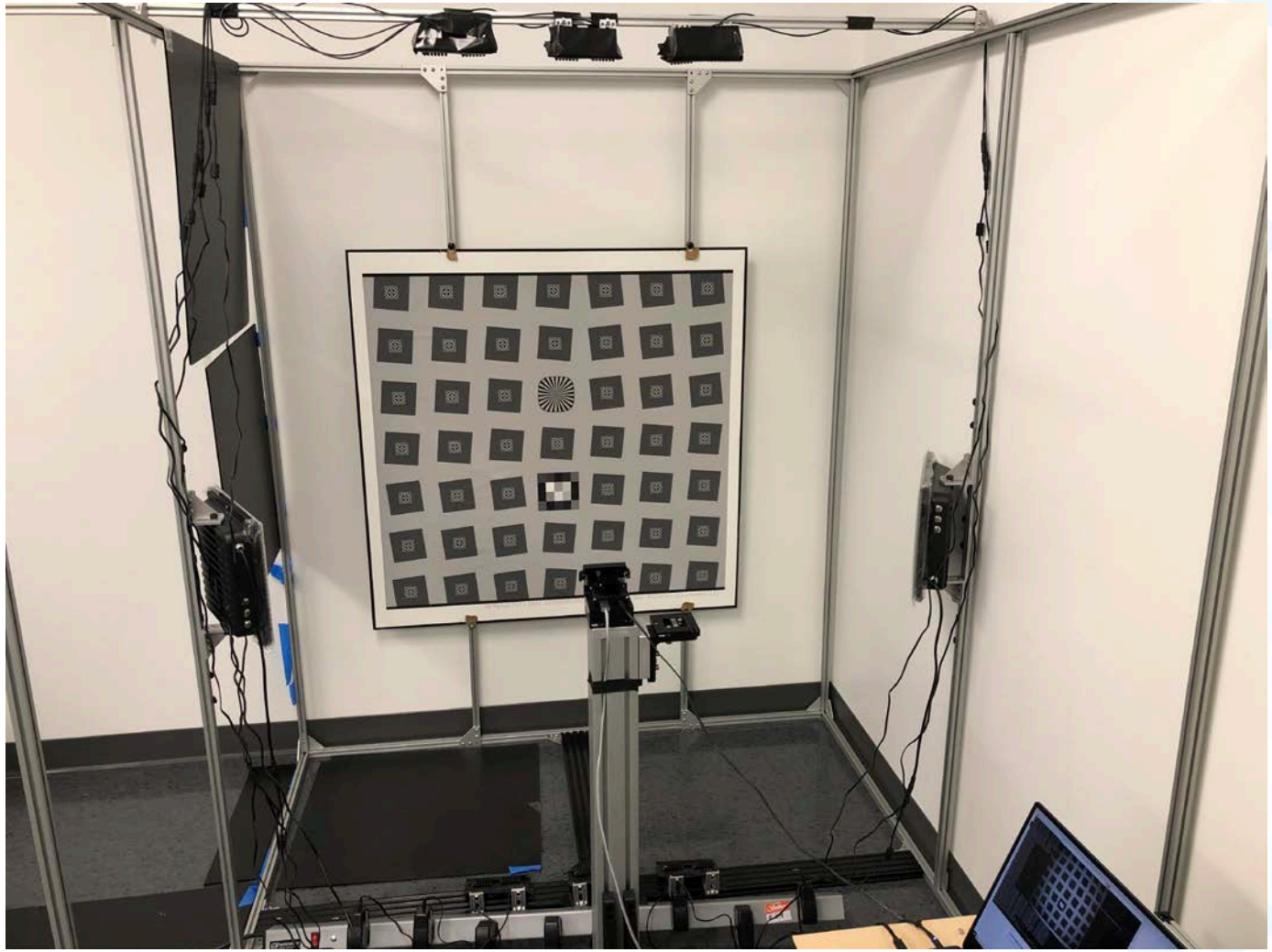


Lens Focus

- Purpose
  - Adjust lens focus for optimum image quality
- Procedure
  - Operate ToF camera in passive IR mode
  - Use passive NIR illumination to uniformly illuminate a focus target chart
  - Set camera-target distance (determined by desired range of focus)
  - Rotate lens in barrel until optimum performance is achieved (e.g. MTF and slanted edge profile)
  - Fix lens in place with threadlocker/adhesive
- ADI currently use Imatest SFRplus focus chart and software for focus adjustment
  - See image of chart and results on the right, illumination not optimized for this measurement

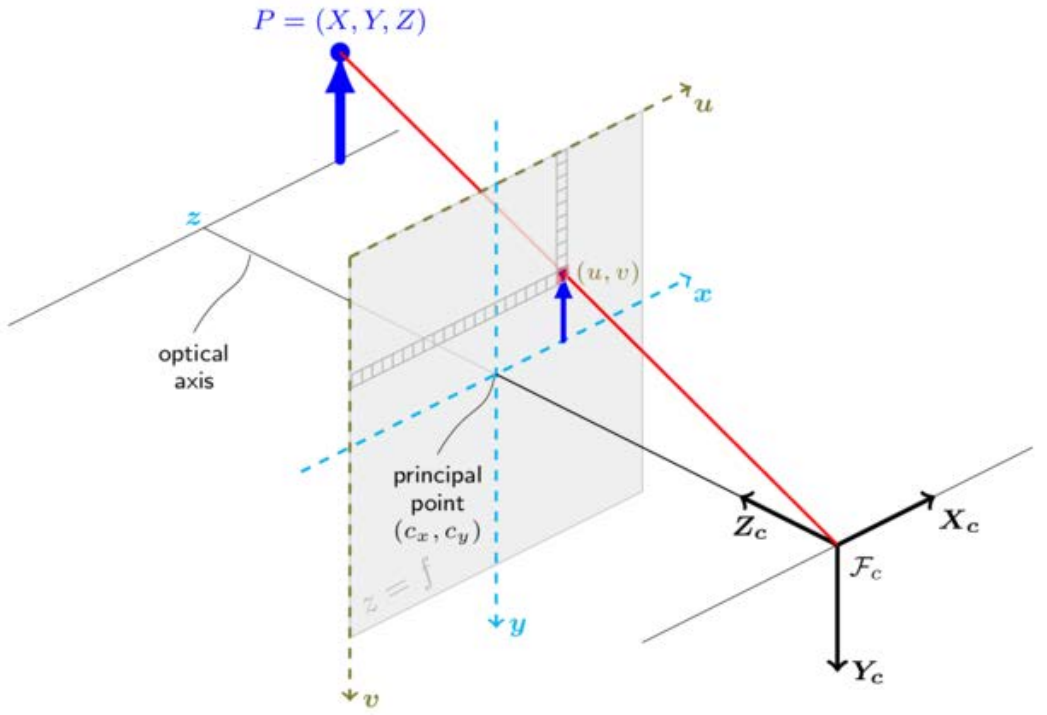


Focus Station (engineering)



Geometric Calibration

- Purpose
  - Estimate the distortion parameters of the lens and image sensor
  - Used to correct for lens distortion and to convert radial depth measurements into real world XYZ coordinates of the 3D image
- Procedure
  - Use open source geometric calibration algorithm such as the OpenCV pinhole camera model
  - Setup similar to lens focus with passive IR images captured using passive NIR illumination
  - Capture images of checkerboards in different orientations to feed into the OpenCV algorithm
  - Calculate camera intrinsics and lens distortion parameters
  - Generate radial distance to point cloud conversion table to be saved to NVM



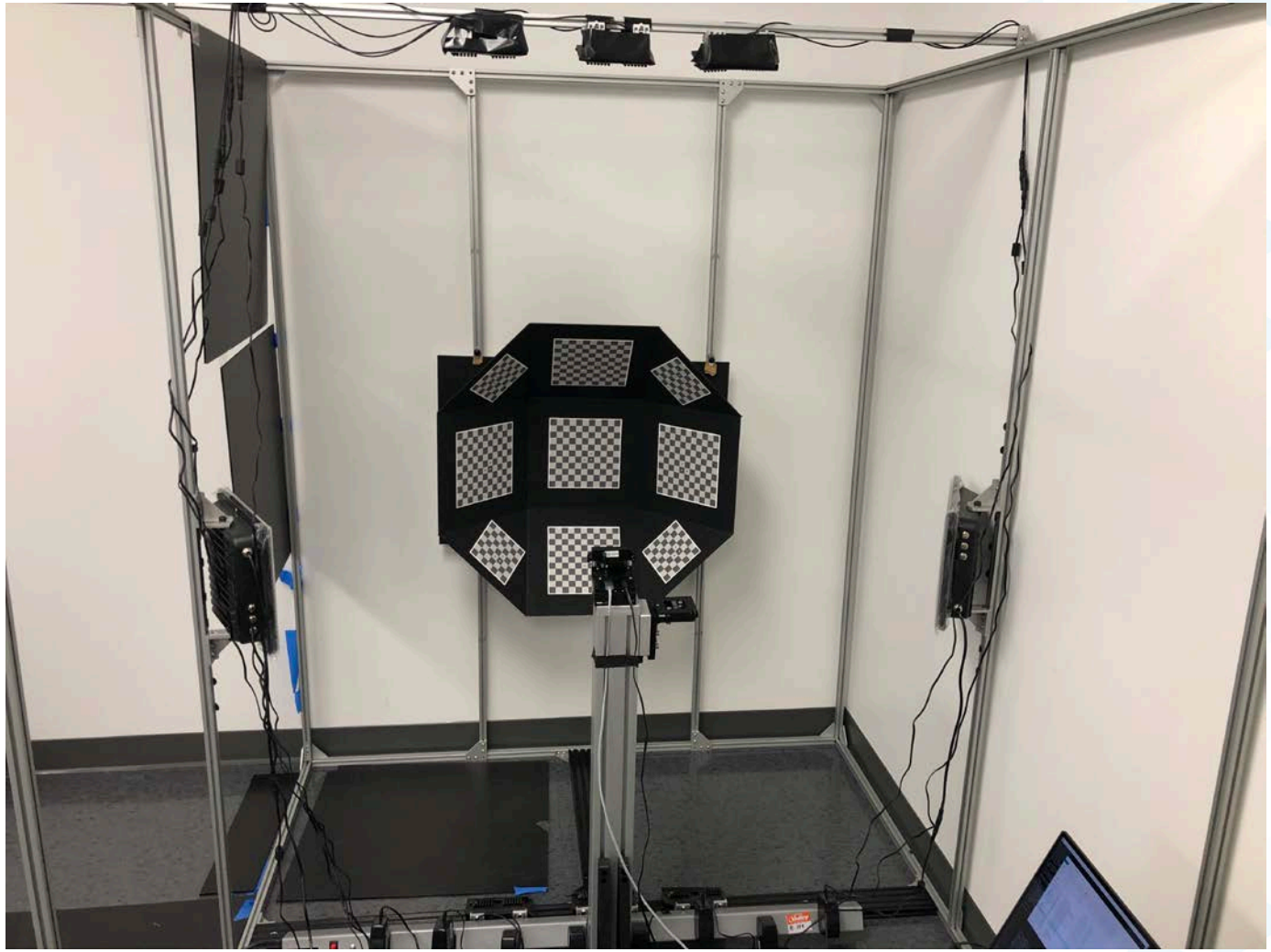
cameraMatrix

$$A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$$

distCoeffs

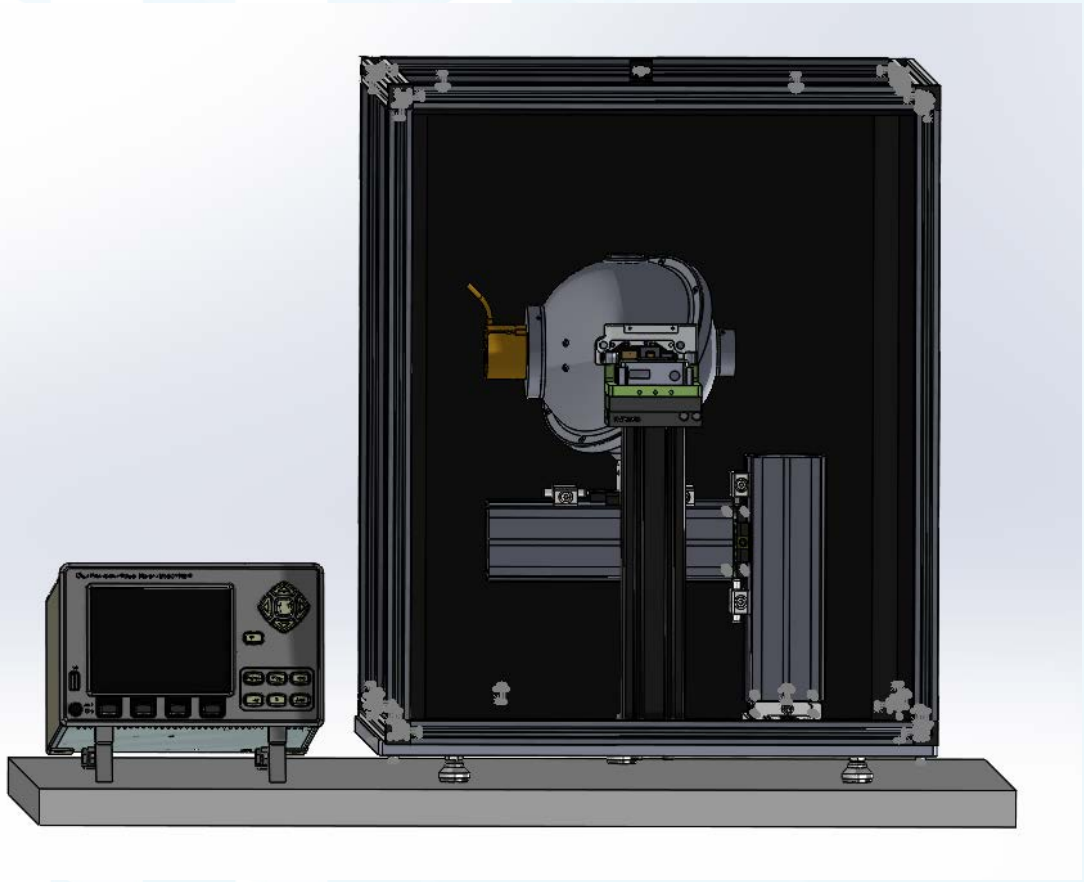
$$(k_1, k_2, p_1, p_2[, k_3[, k_4, k_5, k_6]])$$

Geometric Calibration Station (engineering)

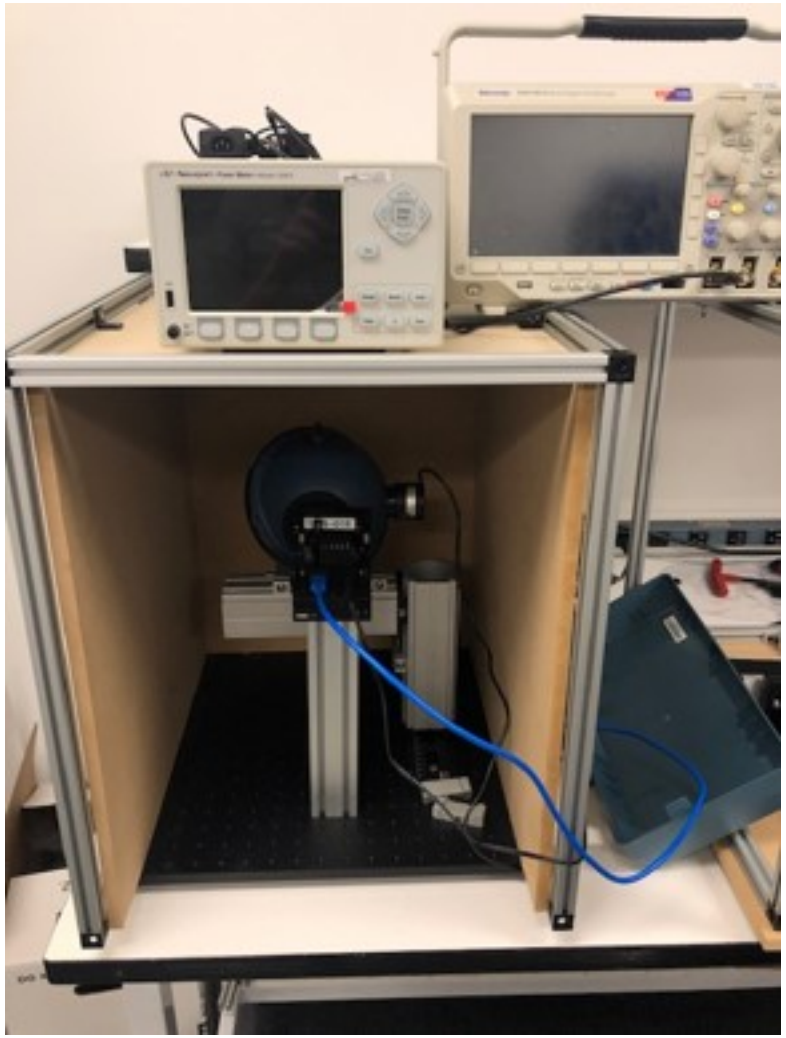


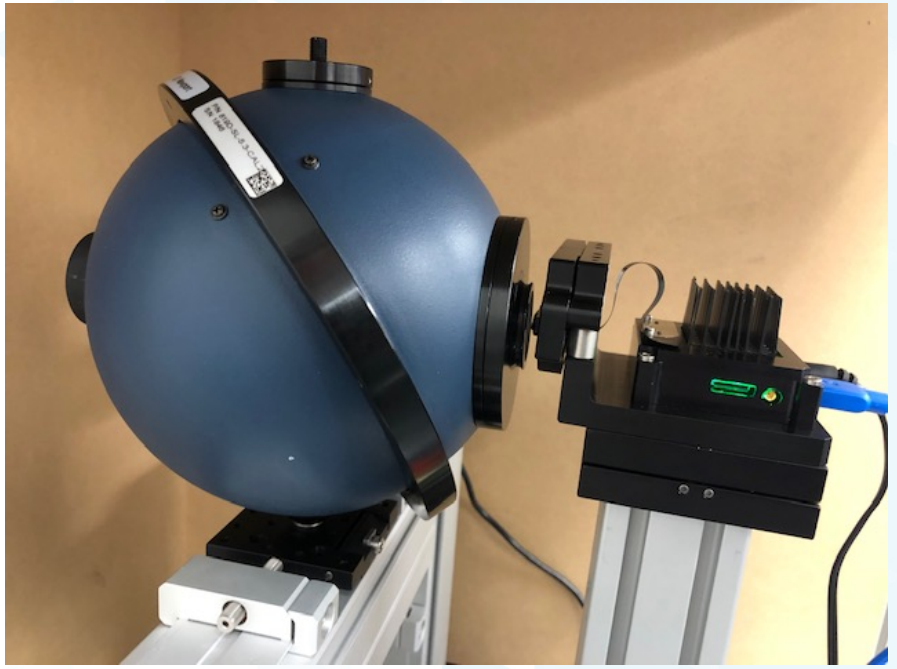
Optical Power

- Purpose
  - Calibrate optical power at each modulation frequency and operating mode to ensure consistent performance and eye safety across all modules
- Procedure
  - ADI use an integrating sphere connected to an optical detector and power meter to perform optical power measurements
  - Measure optical power envelope for each integration period and measure corresponding LD temperature
  - Calculate LD DAC correction factor based on desired optical power at target temperature
  - Store correction factors for the LD driver DAC (one per modulation frequency) in NVM on the module
- Need to characterize optical power over desired temp range in advance to create a model



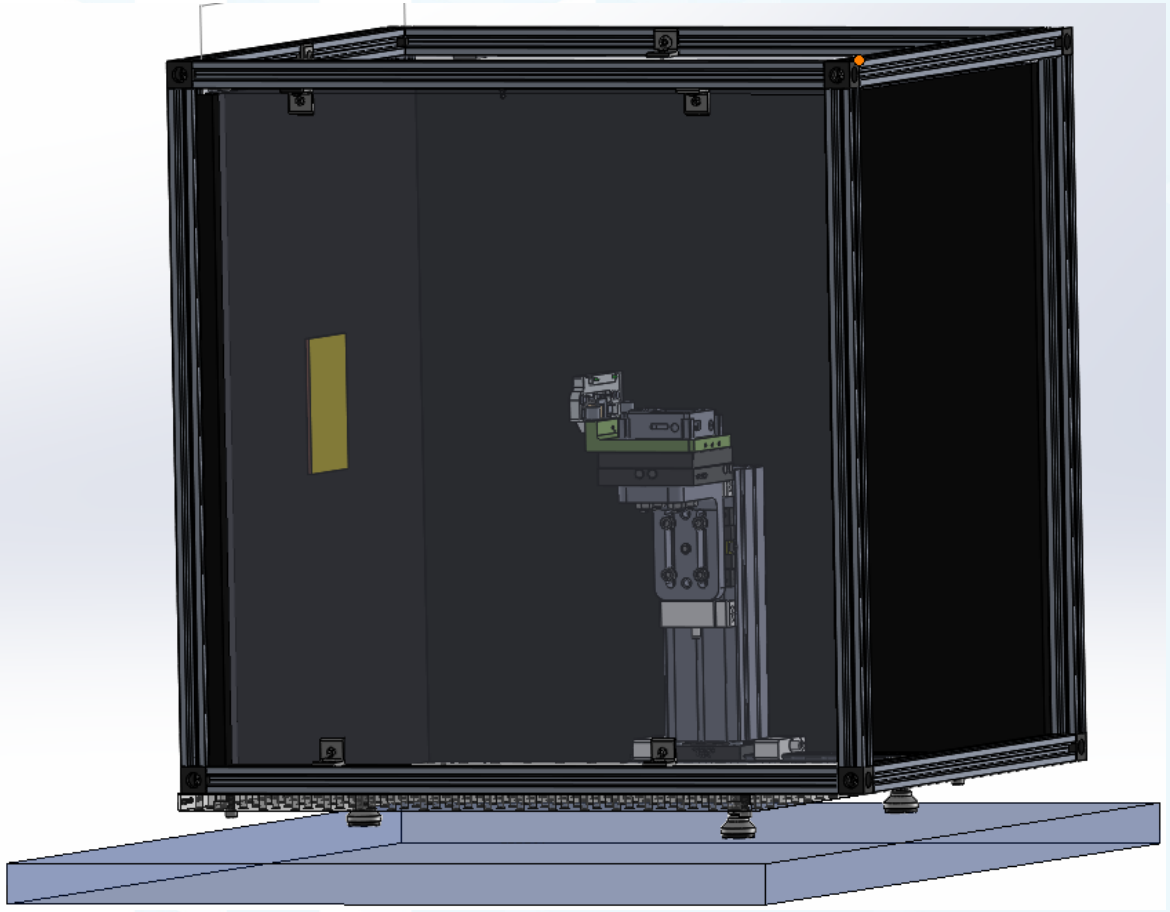
Optical Power Station (engineering)



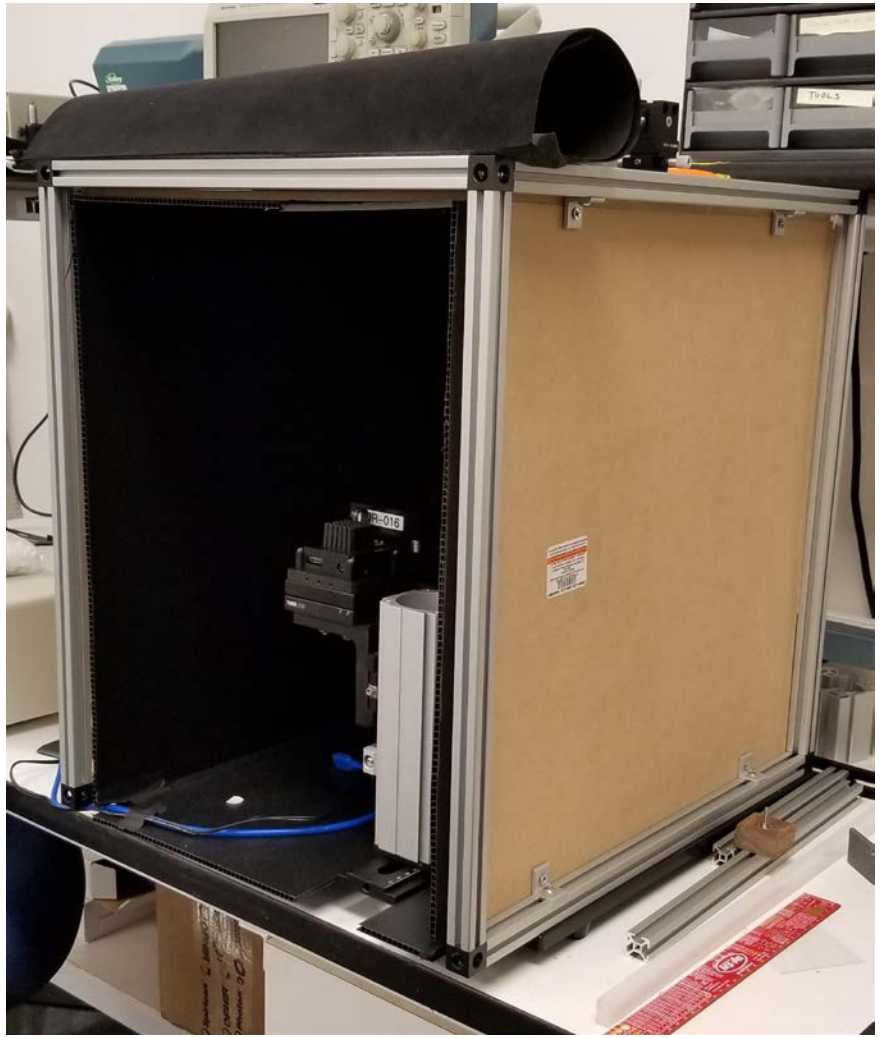


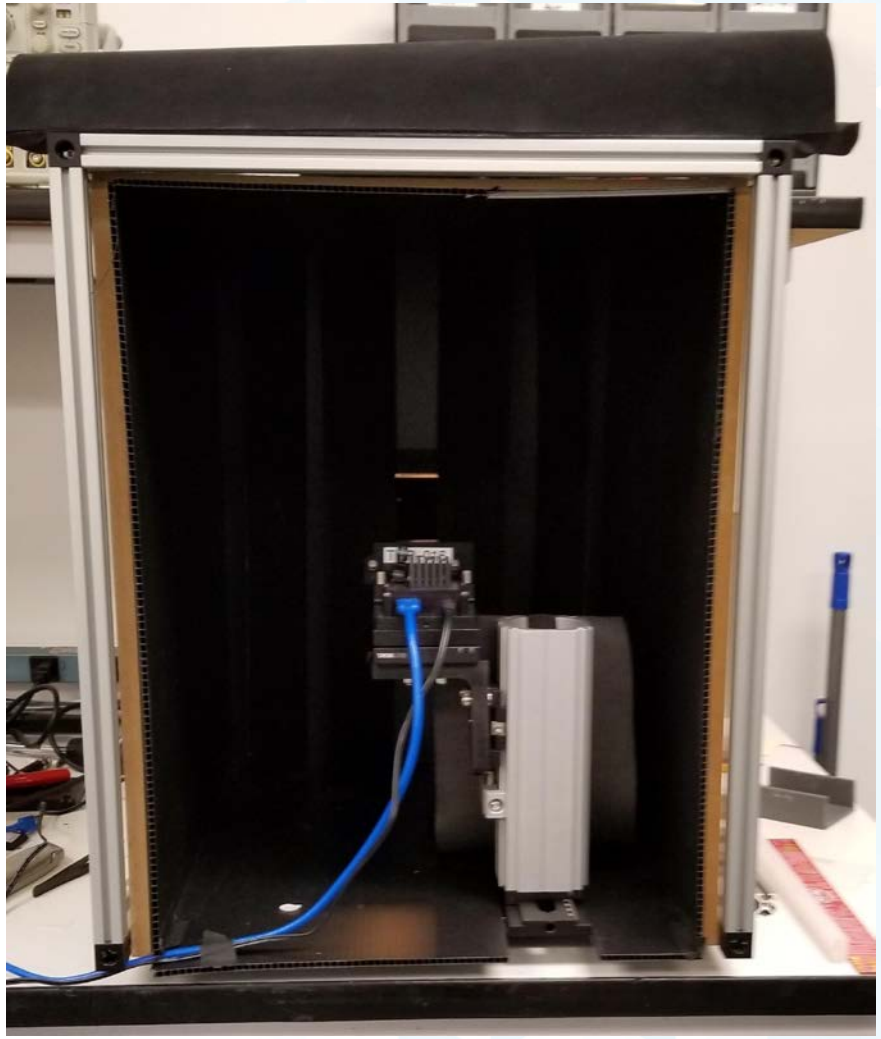
P0 Calibration

- Purpose
  - Remove inherent phase delay for each pixel so the depth engine can provide an accurate depth measurement.
- Procedure
  - P0 phase delay is measured by placing a target at a known fixed distance from the camera.
  - The time of flight is then calculated for each pixel at each operating frequency.
  - Requirement to minimize stray light and reflections within the enclosure so that most of the signal measured by each pixel is the direct path from illumination to sensor via the test target.



P0 Station (engineering)

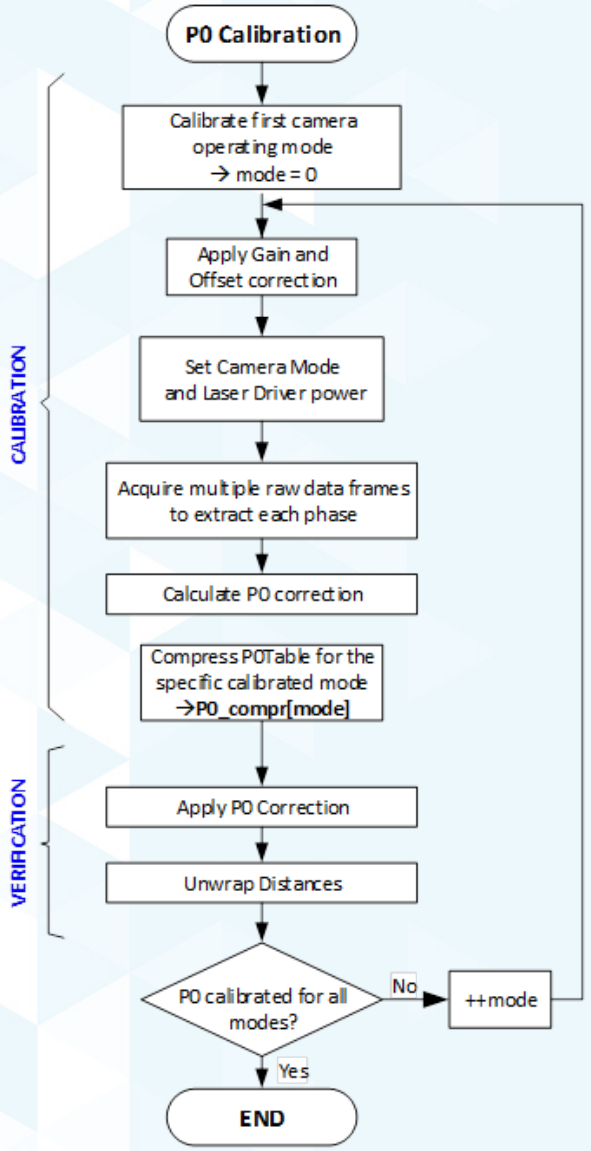




P0 detailed calibration steps

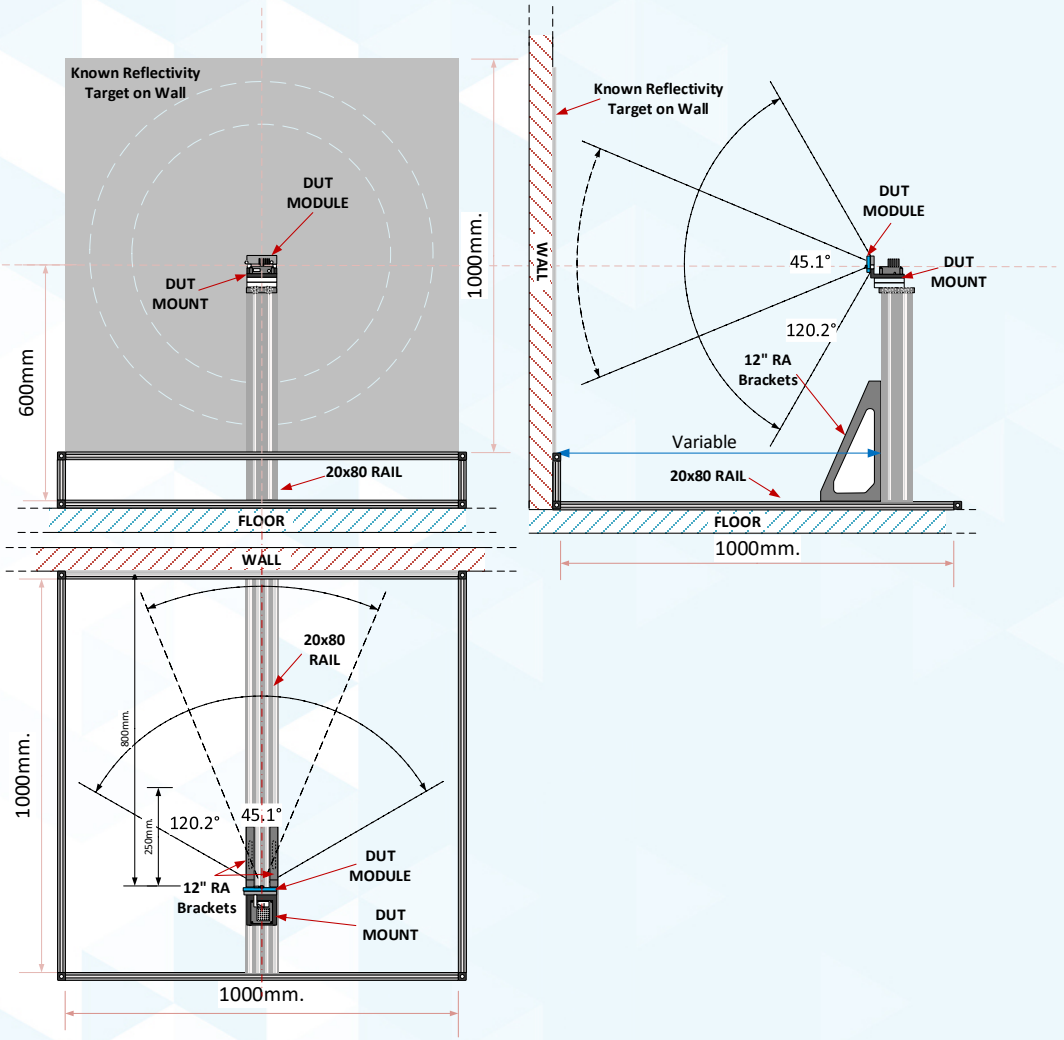
- The P0 calibration process, for a specific mode, is divided in the following steps:
  1. Apply Gain and Offset calibrations
  2. Set the camera operating mode and laser current
  3. Acquire a certain number of test frames (TestPhases)
  4. Use TestPhases data to extract the P0 Table. This is the P0 calibrated data to be compressed and stored in NVM.
  5. From TestPhases frame data, apply the P0 Table to calculate the phases at each frequency supported by the mode.
  6. Unwrap the radial distance
  7. Repeat process, from step #2, for all implemented modes

- The steps 5 and 6 are for verification and data logging purposes



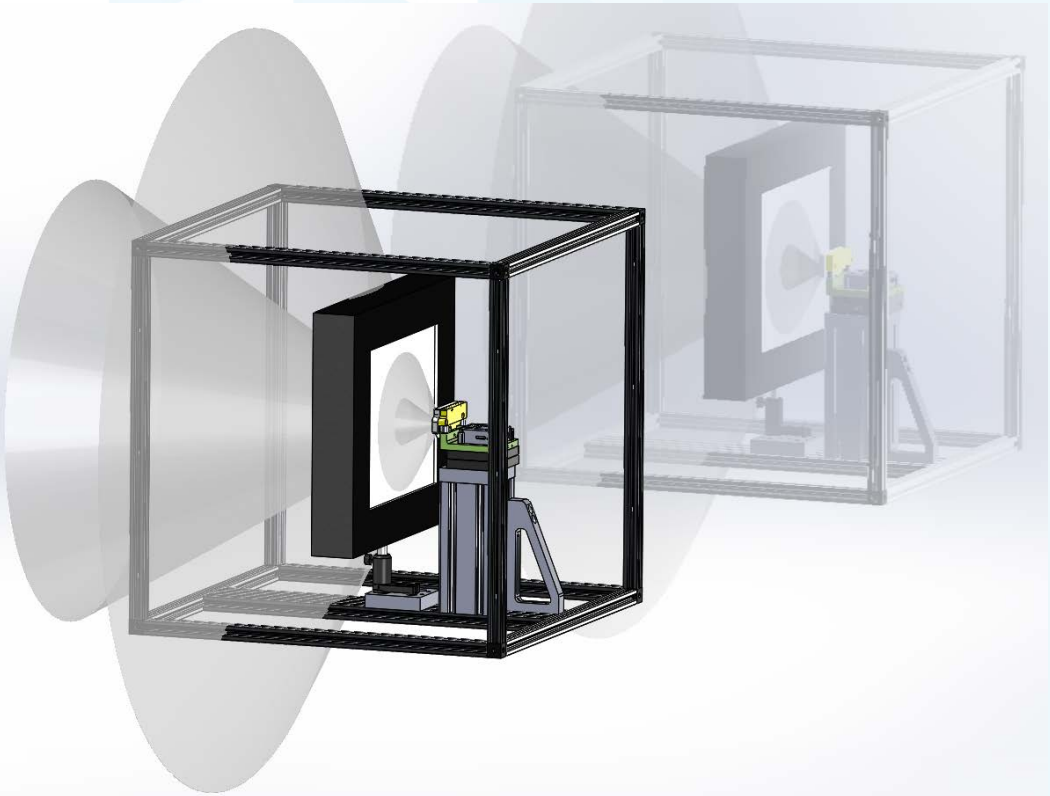
Illumination Profile (Not currently implemented)

- Purpose
  - Check that the laser diffuser is operating correctly
    - Ensure there are no hotspots in the beam profile
    - Ensure eye safety
- Procedure
  - After peak optical power levels have been calibrated, check that the beam profile is uniform
  - The test can be a simple verification of the illumination profile on a flat wall
  - If the wall has a known reflectivity, then the signal levels in the active brightness image can also be verified

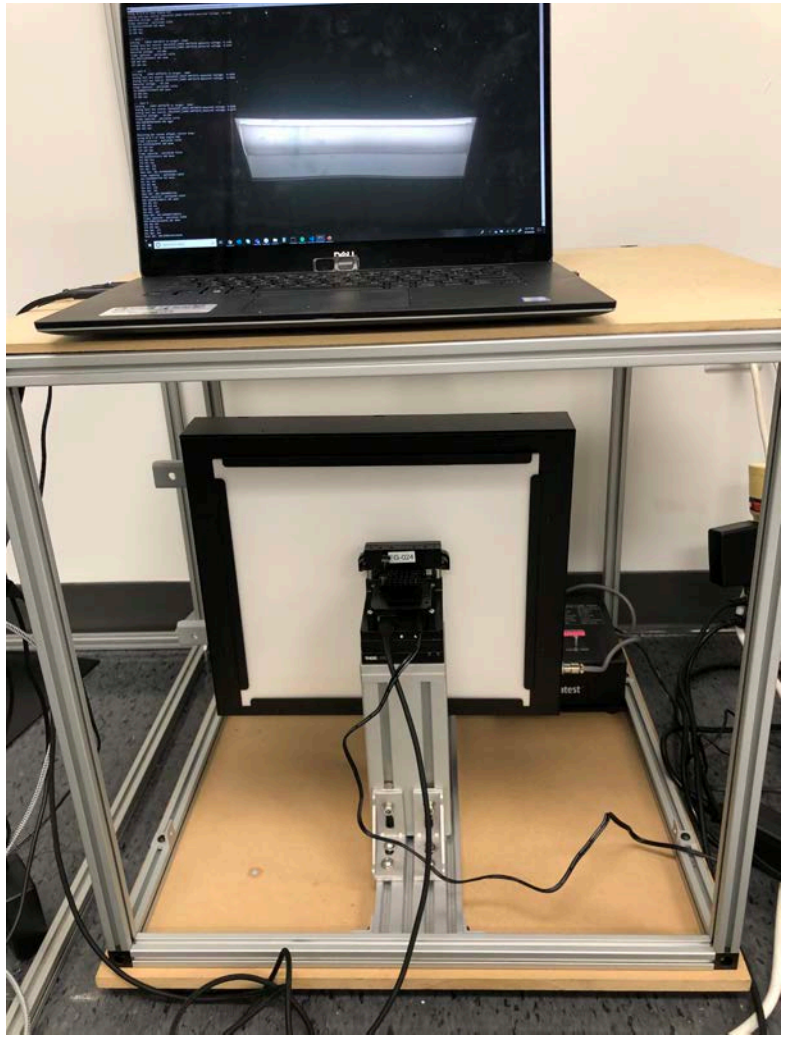


Blemish Test (Optional – recommended initially)

- Purpose
  - Verify no hot spots, dark pixels, or uniformity issues across the surface of the image sensor (e.g. manufacturing defects or assembly contamination)
  - Verify gain and offset calibration by checking operation at different illumination levels
- Procedure
  - Use uniform NIR light panel such as Imatest ILP-B
  - Place camera close to light panel so only the panel is imaged in passive IR mode
    - Check uniformity of the passive IR image
    - Check for clusters of dark pixels
  - Verify gain and offset calibration by sweeping illumination intensity to ensure the sensor doesn't saturate across the desired range
- The blemish test and Gain&Offset verification are additional optional quality checks. They do not have any impact on camera performance.



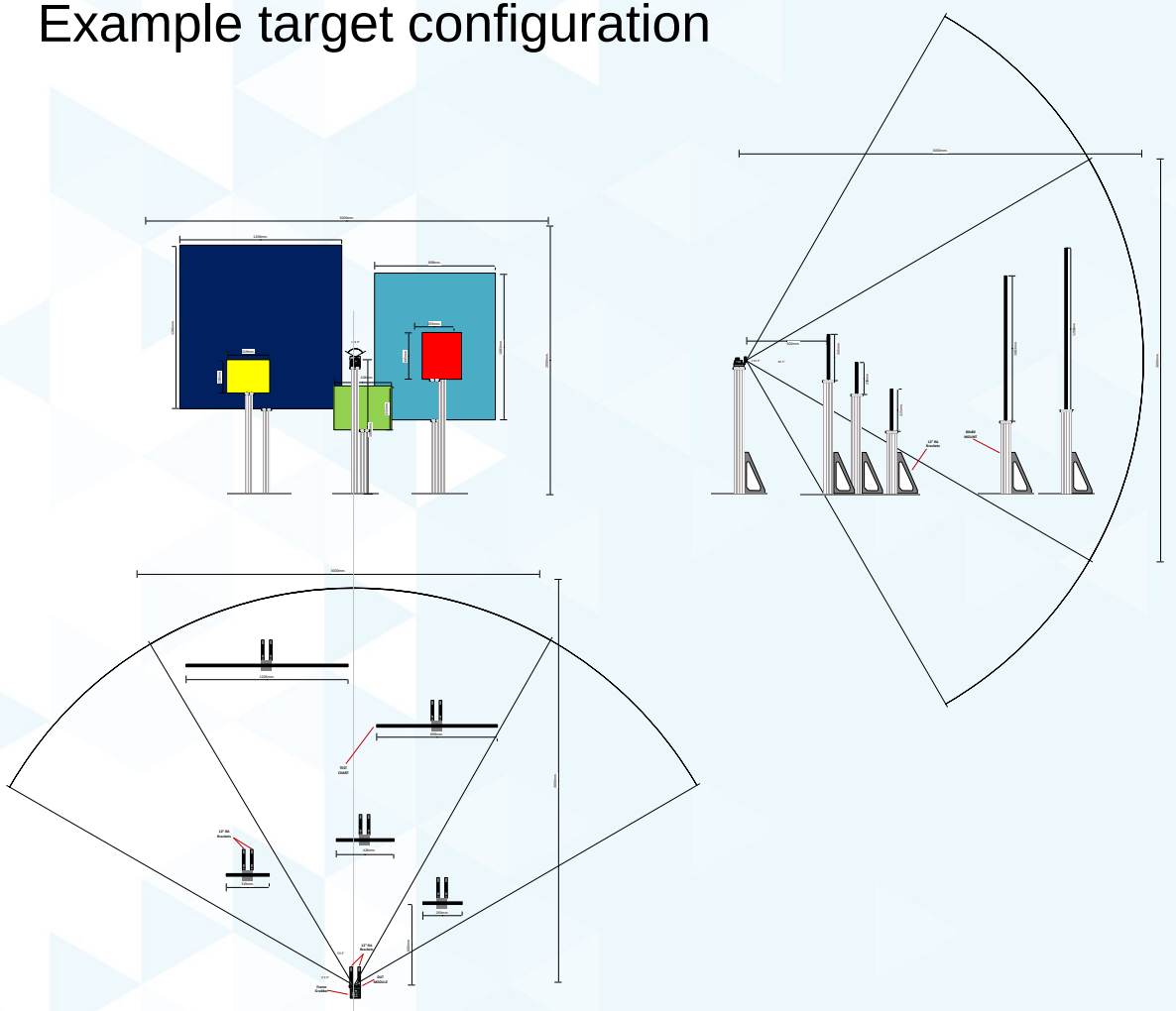
ADI Blemish station (engineering)



Final Check (Optional – recommended initially)

- Purpose
  - Verify depth measurement performance across a desired range with targets at known distances
  - Verify all the preceding calibration pipeline steps were performed correctly
- Procedure
  - Set up targets at known distances for a desired FOV and depth range.
  - Capture depth images of the known scene and verify depth measurements at different locations
- The final check verification is an additional optional quality check. It does not have any impact on camera performance.

Example target configuration



Example Station BOMs

FOCUS STATION - BOM			
Item	P/N	Vendor	Qty
Framing Rail 20x20x1500	20-2020	80/20.net	12
Framing Rail 20x20x1800	20-2020	80/20.net	8
Guide Rail 20x80x1500	225-LP	OpenBuilds	1
Guide Rail 20x40x710	20-2040	OpenBuilds	2
DUT post 80x80x800 + M8 taps	40-8080	80/20.net	1
Cube Corner Connector	941	OpenBuilds	8
Right Angle 12" Bracket	BRK120	Base Lab Tools	2
Mount adapter 80x80x19 (machined)	40-2141	80/20.net	1
Magnetic Base 3" x 3" (Bottom)	KBB3X3	Thorlabs	1
M5 Flat T-Nut	14122	80/20.net	106
M5 Roll-in T-nut	13084	80/20.net	8
20 series Flat Plate 8-hole	20-4165	80/20.net	2
20 series Flat Plate 4-hole	20-4167	80/20.net	2
20 series Inside Corner Bracket	20-4119	80/20.net	8
L Shaped Joining Plate for 2020	20-4081	80/20.net	20
Button socket screw M5x0.8 x 8mm	92095A207	McMaster-Carr	40
M6 T-Nut, spring leaf	13093	80/20.net	4
Straight Line Connector for 2020	2115-Pack	OpenBuilds	2
Screw Socket Cap M5-0.8 x 10mm	92095A208	McMaster-Carr	130
Screw Socket Cap M5-0.8 x 25mm	92095A216	McMaster-Carr	4
Socket head screw M8x1.25 x 20mm	91292A147	McMaster-Carr	3
1/4" washer 0.5" OD	90313A203	McMaster-Carr	4
Socket head cap screw 1/4"-20 x 3/4"	92196A540	McMaster-Carr	4
Socket head screw M6x1 x 16mm	92192A135	McMaster-Carr	2
No 10 screw size washer	92141A011	McMaster-Carr	2
Button socket screw M5x0.8 x 25mm	91292A129	McMaster-Carr	2
Network Mini PC			1
IR Flood Lamps - 850nm-940nm	IRS324-850940	CMVision	2
Light Dimmer (e.g. PSU)			2
Diffuser	36619	Edmund Optics	2
Focus Chart 1200x800	SP00256-NIR	Imatest	1

OPTICAL POWER STATION (#3)			
Item	P/N	Vendor	Qty
Framing Rail 20x20x500	20-2020	80/20.net	8
Framing Rail 20x20x412	20-2020	80/20.net	4
Construction rail 66x200	XT66-200	Thorlabs	2
Construction rail 2"x10" + 1/4" taps	2020-S	80/20.net	1
Guide Rail 66x250	XT66SD-250	Thorlabs	1
Dovetail Plate	XT66P2	Thorlabs	3
Optical breadboard 18"x18"	MB18	Thorlabs	1
Rail Platform Positioner	XT66N	Thorlabs	3
Rail Platform Return Positioner	XT66N1	Thorlabs	3
Cube Corner Connector	941	OpenBuilds	8
Magnetic Base 3" x 3" (Bottom)	KBB3X3	Thorlabs	1
0.5" optical post, L=1"	TR1	Thorlabs	1
Integrating Sphere + detector	819D-SL-5.3-CAL2	Newport	1
Power meter	1936-R	Newport	1
MDF 1/2" thick	1001283615	Home Depot	3
MDF 1/4" thick	1001283607	Home Depot	1
Socket head screw 1/4"-20 x 3/8"	92196A535	McMaster-Carr	1
Socket head screw 1/4"-20 x 5/8"	92196A539	McMaster-Carr	9
Socket head cap screw 1/4"-20 x 3/4"	92196A540	McMaster-Carr	4
Socket head cap screw M3x0.5 x 12m	91292A114	McMaster-Carr	8
Button socket screw M5x0.8 x 8mm	11-5308	80/20.net	3
Button socket screw M5x0.8 x 10mm	97763A820	McMaster-Carr	36
Socket head screw M5x0.8 x 16mm	91292A126	McMaster-Carr	4
Wood screw No. 6 size 1/2"	93360A220	McMaster-Carr	15
1/4" washer 0.5" OD	90313A203	McMaster-Carr	6
Adjustable breadboard feet	BMF4	Thorlabs	3
Aluminium spacer M5 screw x 3mm	94669A069	McMaster-Carr	8
M5 Roll-in T-nut	13084	80/20.net	4
M5 Flat T-Nut	14122	80/20.net	15
20 series Inside Corner Bracket	20-4119	80/20.net	15
Duvetyne 20sq-ft	AGG1601	Amazon	20
Network Mini PC			1

BLEMISH + GAIN/OFFSET STATION (#2)			
Item	P/N	Vendor	Qty
Framing Rail 20x20x500	20-2020	80/20.net	12
Guide Rail 20x80x500	165-LP	OpenBuilds	1
DUT post 80x80x180 + M8 taps	40-8080	80/20.net	1
Mount adapter 80x80x19 (machined)	40-2141	80/20.net	2
Magnetic Base 3" x 3" (Bottom)	KBB3X3	Thorlabs	1
3060 corner bracket	Walfront-052901	Amazon	2
Cube Corner Connector	941	OpenBuilds	8
1/2" Post holder	UPH2	Thorlabs	1
1/2" post x 75mm	TR75/M	Thorlabs	1
Lightbox	ILP-B	Imatest	1
Button socket screw M5x0.8 x 10mm	97763A820	McMaster-Carr	60
Wood screw No. 6 size 1/2"	93360A220	McMaster-Carr	20
20 series Inside Corner Bracket	20-4119	80/20.net	20
M5 Flat T-Nut	14122	80/20.net	39
20 series Flat Plate Bracket	20-4165	80/20.net	2
No 10 screw size washer	92141A011	McMaster-Carr	6
Socket head screw M5x0.8 x 18mm	91292A127	McMaster-Carr	1
Socket head screw M8x1.25 x 20mm	91292A147	McMaster-Carr	3
1/4" washer 0.5" OD	90313A203	McMaster-Carr	4
Socket head cap screw 1/4"-20 x 3/4"	92196A540	McMaster-Carr	4
M6 tnut with spring	13093	80/20.net	2
Socket head screw M5x0.8 x 16mm	91292A126	McMaster-Carr	2
Socket head screw M6x1 x 16mm	92192A135	McMaster-Carr	2
MDF 1/2" thick	1001283615	Home Depot	3
MDF 3/4" thick	1001283617	Home Depot	1
MDF 1/4" thick	1001283607	Home Depot	1
Duvetyne 20sq-ft	AGG1601	Amazon	20
Network Mini PC			1

References

- ADI Engineering Calibration stations – contact ADI for more info on:
  - CAD files
  - Station setup/configuration
  - Other vendor information (equipment, targets, etc.)

- Documentation
  - ADSD3100 Camera Calibration Overview
  - ADSD3100 Frame Grabber Manual
  - ADSD3100 Datasheet
  - ADSD3100 Module Design Guide
  - ADSD3100 Module Bring-Up