ToF Camera Calibration Overview **ADSD3100**

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Revision History

04/2020 – **Rev. B: Added more details including recommended station BOMs**

11/2019 – **Rev. A: Initial version**

Acronyms

Acronym	Definition
ADC	Analog-to-Digital Converter
DAC	Digital-to-Analog Converter
ADI	Analog Devices Incorporated
CAD	Computer Aided Design
CW	Continuous Wave
FOV	Field of view
I2C	Inter integrated circuit
LD	Laser diode
NIR	Near Infrared
NVM	Non-volatile Memory
MIPI	Mobile industry processor interface
MTF	Modulation Transfer Function
PSU	Power Supply Unit
REG	Regulator
SPI	Serial protocol interface
TOF	Time-of-flight
VCSEL	Vertical cavity surface emitting laser

1 Overview

This document describes the different calibration routines required for the ADSD3100 ToF camera module. The calibration stations required for a functional module are described at a high level, along with example CAD drawings and BOM for each station. There are also some details on additional calibration stations that could be considered for additional quality checks.

The details on each of the calibration stations are based on the ADI lab setup designed for low volume testing of engineering modules. It is expected that some of the stations would be modified and optimized for higher volume production environments. The document attempts to highlight the key elements of each calibration station that should be considered when developing a production solution.

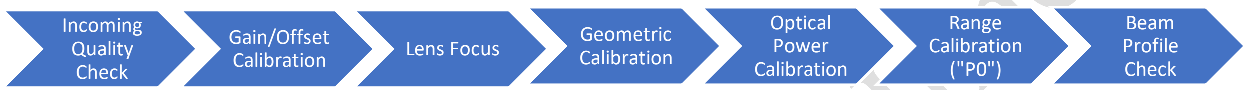

Figure 1: ADSD3100 engineering module calibration flow

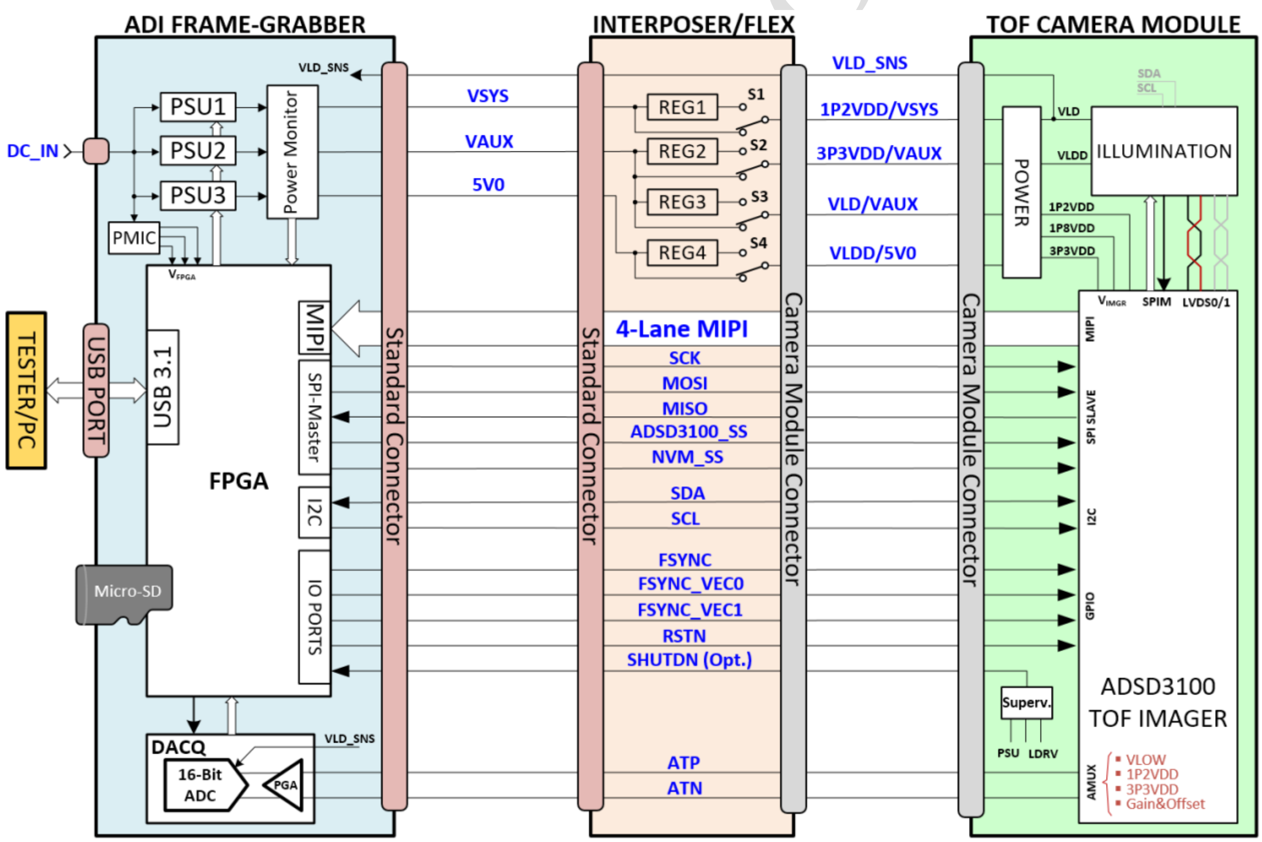

Figure 2: TOF Module Calibration Setup

2 General Requirements

In the ADI lab setup, shown in Figure 2, the ADSD3100 module is connected via a flex cable, or interposer board, and FFC connector to a “Frame Grabber” that acts as the mechanical mount for the module as well as the host processor. Depending on the power architecture implemented in the TOF module, the flex/interposer may need on-board regulators supplied and monitored from the frame grabber.

The frame grabber is used to setup the module, initiate frame captures, process frames before sending them to a PC, and write calibration data to the non-volatile memory on the module. The frame grabber is powered via wall wart and has a USB connection to a PC. Other hosts/mechanical mounts could also be used in place of the ADI frame grabber, but for the purpose of this document the frame grabber will be used in the calibration station descriptions.

The calibration stations can have dedicated frame grabbers in which case only the module is moved between stations, or the frame grabber and module can be moved together between stations. Each station can either have a dedicated PC or a centralized networked PC can be used to communicate with all stations.

The ADI lab setup uses a frame grabber connected to a Thorlabs KBT3X3 mount which is moved between stations. Each station has a matching Thorlabs KBB3X3 kinematic base which the frame grabber mount connects to magnetically. This ensures the alignment of the module is always correct after mounting the frame grabber at the new station. A sketch of the frame grabber and Thorlabs magnetic base is shown in Figure 3.

Calibrations must be performed in a temperature-controlled environment at a fixed temperature (typically 25 °C). Local temperature inside the module, imager and illumination circuit, must be monitored to be within limits and logged in the calibration data file.

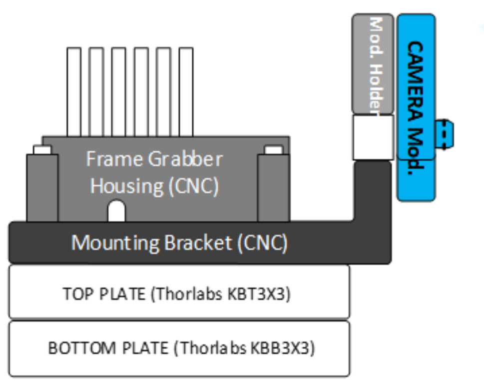

Figure 3: Frame grabber and mounting base

The Thorlabs ¼”-20 mount is not compatible with the 80x80mm mounting posts used at some of the calibration stations, so in those cases a custom machined 40-2141 mounting plate (from 80/20 Inc.) is used to interface between the imperial and metric mounting holes. The 40-2141 mounting plate has 4 x M12 tapped holes which can be used to connect to the 80 x 80 mm mounting post. An additional 8 x ¼”-20 tapped holes need to be added as shown in Figure 4 to be used for mounting the Thorlabs KBB3X3 base.

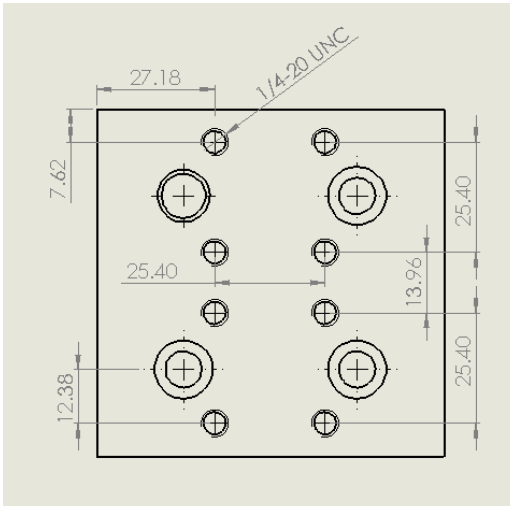

Figure 4: Custom machined 40-2141 mounting plate

A software calibration pipeline has also been developed to run all the ADI calibration stations. This consists of a UI (user interface) to initiate each specific calibration. The results of each calibration station are stored in a log file on the PC, along with the module ID of the module under test. The software calibration pipeline is available to customers and contract manufacturers as a reference if required. Some of the calibration routines (e.g. gain and offset calibration, P0 calibration) are proprietary and can therefore only be delivered as binary libraries or executables.

3 Calibration Stations

The calibration stations are described in the following sections. Some of these stations may be modified or combined for a production environment, but each of the calibrations is required to obtain the best module performance.

3.1 Incoming Quality Check (IQC)

The module should be checked to ensure it is electrically functional before going through the calibration pipeline. The frame grabber has measurement circuitry to perform basic electrical tests on power supply voltages, clock/PLL frequencies, and to verify MIPI streaming from the image sensor. There no need for additional equipment and the incoming quality check can be performed before calibration or at the first calibration station.

3.1.1 Power Supply Checks

The ADI frame grabber has power monitors to measure the voltage and current on each of the module power rails. It can also be used to send commands to configure the ADSD3100 to output internal signals on analog test pins (ATP and ATN) so that they can be measured on the frame grabber to verify correct operation. Note, the incoming quality checks should be performed without active illumination for eye safety reasons, since optical power calibration has not been performed on the module yet. Later in the calibration pipeline after the optical power calibration has been performed, the supply rails can be monitored in normal operation to verify power supply rails are behaving as expected.

The power supply tests and configurations are detailed in Table 1.

Test	Typ	Comment
Vmain Imain	4.2V <200mA	INA231 power monitor on frame grabber board
Vsys Isys	4.2V <50mA	INA231 power monitor on frame grabber board
Vaux Iaux	27V <50mA	INA231 power monitor on frame grabber board
Vdepth Idepth	5.3V <50mA	INA231 power monitor on frame grabber board
V1p2	1.27V	ADS1115 ADC measures ADSD3100 ATP pin Write 0x7 to device address 0x0160 to configure ATP output Configure ADS1115 ADC for single ended ATP measurement
VHIGH	3.3V	ADS1115 ADC measures ADSD3100 ATP pin Write 0x8 to device address 0x0160 to configure ATP/ATN Configure ADS1115 ADC for single ended ATP measurement
VLOW	1V	ADS1115 ADC measures ADSD3100 ATN pin Write 0x8 to device address 0x0160 to configure ATP/ATN Configure ADS1115 ADC for single ended ATN measurement
VLD	7V	AD5593R ADC measures divided down LD voltage

Table 1: Incoming Quality Check power supply tests

3.1.2 MIPI streaming verification

After verifying that all voltages and currents are within limits, the ADSD3100 module is programmed to operate in passive mode which triggers the capture of IR images. The frame grabber acquires few frames through the MIPI interface to validate the ADSD3100 imager operation. This test verifies the streamed video data quality.

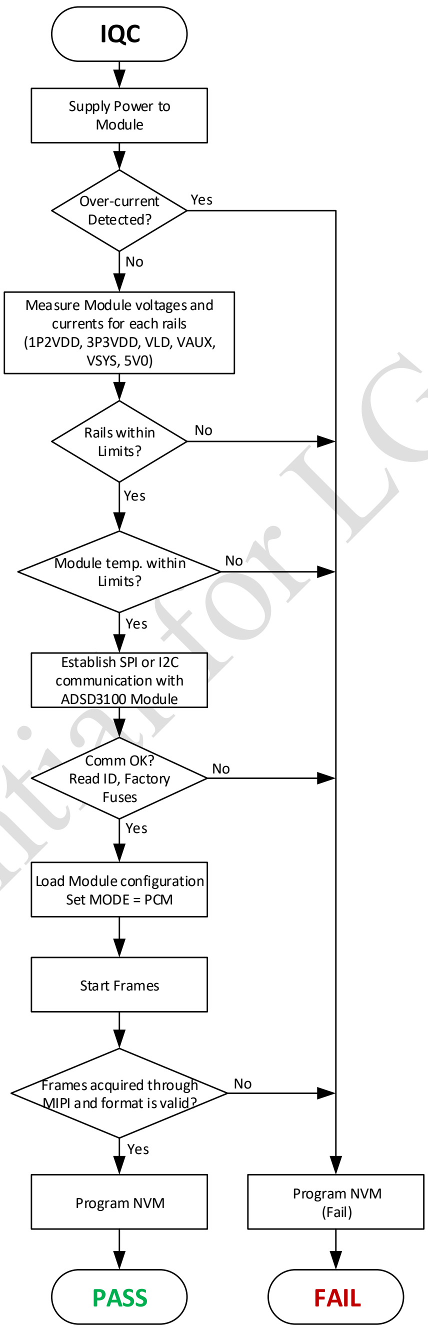

Figure 5: IQC Flow-chart

3.2 Gain and Offset Calibration

The gain and offset of amplifiers and column ADCs, internal to the sensor, are calibrated to remove column fixed pattern noise in the captures and to ensure that the largest measurement range can be achieved across the image sensor without saturating the column ADCs. Before proceeding with the gain and offset calibration, the ADSD3100 internal VLOW step-down regulator should be tested and adjusted to operate within the datasheet limits. VLOW can be measured though the analog test interface (pins ATP and ATN).

The gain and offset calibration does not require a dedicated calibration station or any dedicated hardware (other than the frame grabber that control the camera and captures frames). For this reason, the gain and offset calibration is typically performed at one of the initial calibration stations (e.g. after incoming quality check or at lens focus station, just before performing the lens focus calibration). The performance post-calibration can be validated with the lightbox at the blemish station (if implemented).

A generic gain and offset calibration setup is shown in Figure 6. The ADSD3100 is programmed, via SPI or I2C interface, to operate in a special test mode where the pixel bitline voltage is replaced by internal DACs via analog multiplexers. Voltages applied to the pixel amplifier can be measured using the analog test mode interface (ATP and ATN pins). This configuration is selected when calibrating the gain transitions according to the applied voltage level. These thresholds are used by a comparator circuit to select between four possible per-pixel gains. The appropriate per pixel-gain is chosen to optimize SNR and to avoid the saturation of the column ADCs. The column ADCs offset and ramp slope are calibrated using the same test circuit. The ADI frame grabber contains the hardware to perform this calibration. ADI also can provide software code to run the gain and offset calibration. When using a dedicated calibration tester rather than the ADI frame grabber, a differential ADC with at least 16-bit resolution and >1KSPS conversion speed, and a programmable amplifier should be used to measure the ATP/ATN pins. The tester must be able to control the module operation including streaming MIPI data during the calibration process. A high-level overview of the gain and offset calibration process is shown in Figure 7.

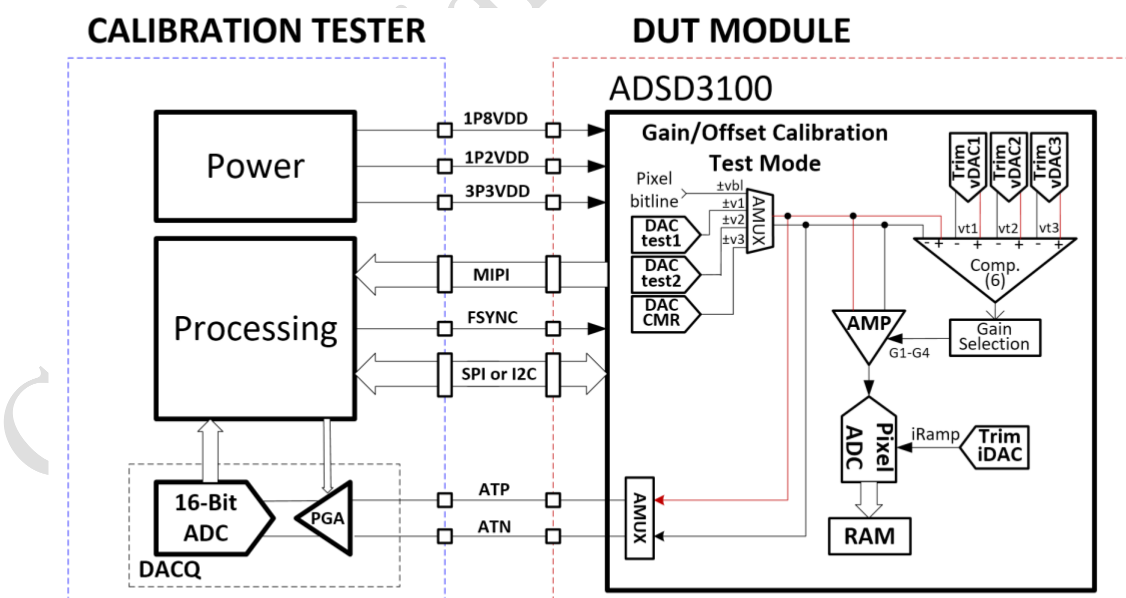

Figure 6: Gain and Offset, generic calibration setup

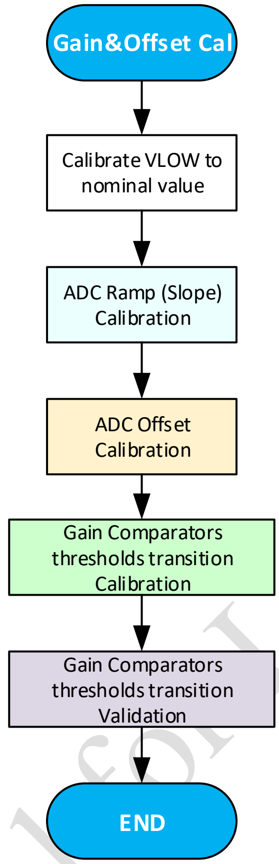

Figure 7: High level, gain and offset calibration flow

3.3 Lens Focus Adjustment

The imaging lens is manually rotated in the lens barrel until the desired focus level is achieved. The focus test is performed with a dedicated focus chart and software that measures the modulation transfer function (MTF) at different points on the focus chart. Edge rise times are another parameter that can be monitored. Passive IR illumination is used to illuminate the chart and the camera captures 2D IR images in passive mode to be used for the focus adjustment.

The calibration station size and focus chart size will depend on the FOV and desired focus distance of the camera. For the ADI lab setup, the station size is approx. 1.5m x 1.5m x 1.8m (to cover multiple different FOV designs) and focus chart size is 24” x 34” (approx. 0.86m x 0.61m)

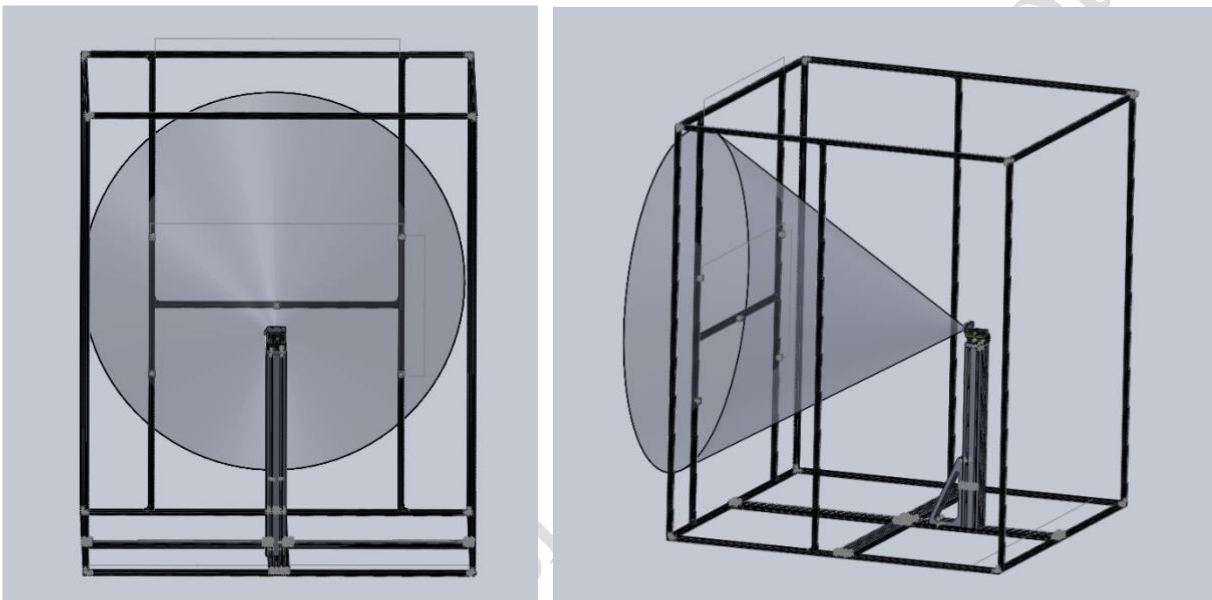

Figure 11: Lens focus adjustment station CAD

The ADI engineering lab setup uses an Imatest SFRPlus focus chart and Imatest software to perform the focus calibration. Several passive illuminated images (e.g. 50 frames) are captures and averaged before feeding into the Imatest software. The Imatest software detects slanted edges in different portions of the FOV and returns the corresponding MTF calculations (e.g. MTF50) and edge rise times.

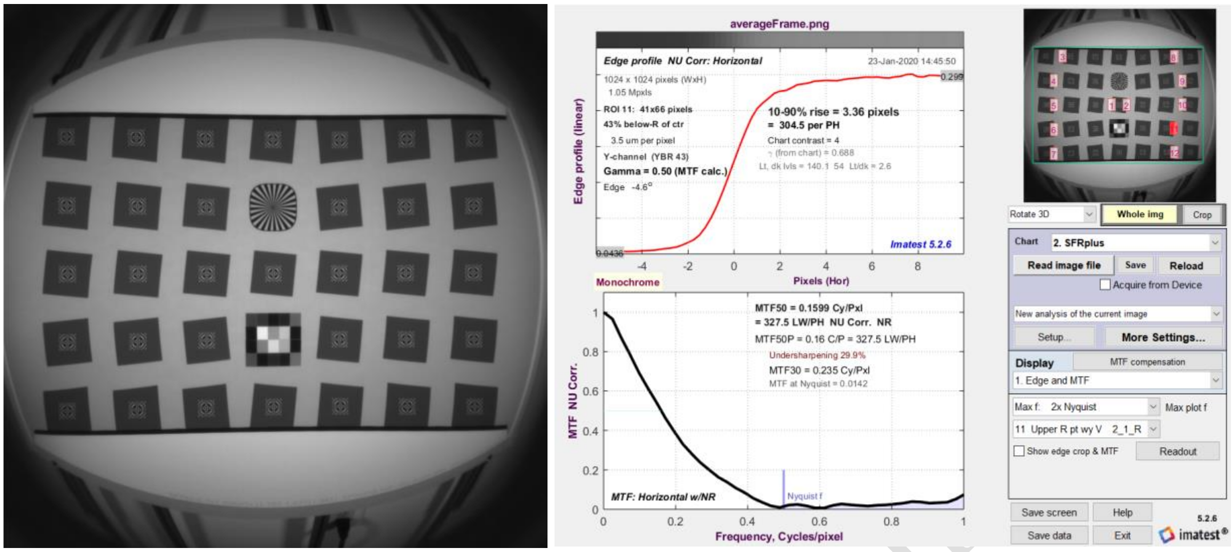

Figure 12: Imatest focus chart and software

The critical parameters for the focus calibration are:

- Distance from camera to focus chart – this should be calculated based on the desired optimum focus distance and desired depth of field of the camera (i.e. min to max focus distance).
- Focus chart – slanted edge charts like the Imatest SFRPlus chart mentioned above are good for automated MTF calculations, but any standard focus chart can be used. The chart should be sufficiently high resolution, should be mounted on a flat substrate, and the ink should be optimized for NIR wavelengths.
- Illumination – the chart needs to be illuminated with an external NIR light source. The light source should be at the correct wavelength (e.g. 850nm or 940nm), the illumination should be uniform across the chart, and the intensity should be set well below the level where any pixels get close to saturation.
    - The Imatest software can be used to show the uniformity of illumination across the chart and optical power levels should be varied to optimize MTF results.
    - The ADI lab setup uses two relatively cheap NIR lamps for passive illumination and diffusers are placed in front of the lamps to improve uniformity across the chart.
- Mechanical alignment and stability – the camera should be mounted perpendicular to the chart at the height of the center of the focus chart. The mechanical structure should be built to ensure the camera and chart are stable during focus calibration, but other mechanical elements are not too critical.

The BOM for the ADI lab setup (see Figure 11) is detailed in Table 2. This can be considered as an example setup; any other approaches are valid if the critical parameters mentioned above are considered. The focus of the ToF camera module is very similar to focusing a 2D visible camera so a similar focus setup can be used if already available. The only changes required would be the passive NIR illumination and a focus chart optimized for NIR wavelengths.

All of the ADI lab setups use regular 6105 grade aluminum T-slot frames rather than black anodized aluminum as there is some literature such as this paper from Texas A&M which suggests reflectance is higher with black anodized aluminum at NIR wavelengths. The paper details how "black anodization is quite reflective at red and near-IR wavelengths (l > 700 nm), and in fact non-dyed ("hardcoat") anodization of aluminum may be a better treatment for instruments that cover a wide wavelength range, particularly if the surfaces are not bead blasted prior to coating." Although reflections from the station cages generally should not be an issue, the preference is to go with regular anodized rather than black anodized as reflectance may be lower and cost is also lower.

The cube corner connectors are listed as optional in the BOM. They can make assembling the frame easier but using them adds a requirement to add a single M5 end tap on each side of the framing rails. This service can be provided by 80/20.net at an additional cost and with increased lead time. It is still recommended to use the L-shaped brackets at the corners for alignment and stability purposes, so the cube corner connectors aren't structurally required. Note, the 80x80 mounting post also requires 4 x M8 taps to connect the mounting base assembly for the frame grabber.

For a production setup, the focus adjustment would likely be automated with servo-motor assistance. The lens will also be glued in place for production modules whereas thread-locker will likely be used on the initial pre-production modules.

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

Table 2: Focus station example BOM

3.4 Geometric Calibration

Geometric calibration estimates the distortion parameters of the lens and image sensor. These parameters are then used to correct for lens distortion and to convert radial distance measurements into world XYZ coordinates of the 3D image. This is required for accurate point clouds or Z-depth maps.

The calibration assumes a pinhole camera model. The following calibration parameters are calculated:

- **Camera Intrinsic Parameters**
  The imager intrinsic parameters include the focal length, optical center (or principal point), and the skew coefficient. The corresponding camera matrix containing the intrinsic parameters is defined as:

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

  (c_x, c_y) = optical center (expressed in number of pixels)
  (f_x, f_y) = focal length (expressed in number of pixels)
  s = pixel skew coefficient (typically close to 0 in most modern image sensors)
- **Distortion parameters**
  The distortion model used by ADI can be found on [the OpenCV website](). Other models are not supported by ADI's depth processing algorithm.
  Radial distortion occurs because light rays bend more near the edges of a lens than at the center of the lens. The radial distortion coefficients model this type of distortion. 6 radial distortion coefficients **(k_1, k_2, k_3, k_4, k_5, k_6)**.
  Tangential distortion occurs when the lens and image plane are not parallel. The tangential distortion coefficients model this type of distortion. The open CV algorithm considers 2 tangential distortion coefficients (**p_1, p_2**)

The pinhole camera parameters **f_x, f_y, c_x, c_y, s** and the lens distortion parameters **k_1, k_2, k_3, k_4, k_5, k_6, p_1, p_2** are estimated by capturing images of a planar calibration targets (e.g. checkerboard pattern) with different orientations/planes relative to the camera. The most popular algorithm is Zhang's algorithm, which has been implemented in many open source computer vision libraries such as OpenCV.

In the ADI lab setup, the size of the calibration station is similar to the lens focus station (e.g. 1.5m x 1.5m x 1.8m) and the geometric calibration is performed with the camera at a similar distance from the target as the best focus is achieved at that distance. The focus station structure can be reused during the prototype and low volume calibration phase by changing the calibration target. The geometric calibration should be performed after lens focus.

The geometric calibration procedure also relies on passive NIR illumination. 2D IR images captured in passive mode are averaged and processed by the distortion estimation algorithm. Since the focus station can be reused for geometric calibration, the same BOM shown in Table 2 is also applicable to the Geometric calibration station, with the exception of the focus chart.

3.5 Optical Power Calibration

The optical power level is measured and calibrated at each operating frequency. This ensures consistent performance and eye safety across all modules and modulation frequencies.

The VCSEL/LD drive signal should be tuned to maximize the amplitude of the fundamental in the Fourier transform of the optical waveform since the time-of-flight measurement is made by extracting the phase of the fundamental of the laser waveform. With a perfectly rectangular optical waveform and 50% duty cycle, this is equivalent to optimizing for maximum average power. Since the real optical waveform will not be rectangular and may not be exactly 50% duty cycle, more care is required in order to optimize the optical power of the fundamental.

Once the optical power of the fundamental has been optimized, the module needs to be characterized over temperature. The temperature model and drive signal tuning only need to be performed during the development phase on a statistically significant number of modules.

After a temperature model is created, the optical power calibration can be performed at a single temperature by monitoring the temperature at the VCSEL/LD (and perhaps the sensor die for a dual temperature model) during the calibration. The laser drive settings can then be configured to guarantee a minimum optical power at the upper temperature extreme for example, or a maximum optical power over the full range of operation if eye safety is the limiting factor. The camera is calibrated at each frequency for each mode of operation.

The ADI calibration is performed by measuring the optical power level with an integrating sphere and optical power meter. Instrumentation control is required for timing synchronization of the meter with the camera illumination. The correction factors for the LD driver DAC at each modulation frequency are stored in NVM on the module. These are then applied in real time for each modulation frequency during camera operation.

The ADI lab setup incorporates the camera module, frame grabber, and a Newport integrating sphere in an enclosure of approximately 0.5m x 0.5m x 0.5m, as shown in Figure 13. This ensures no ingress of light to the integrating sphere from other light sources. There is also a power meter and instrumentation control external to the enclosure.

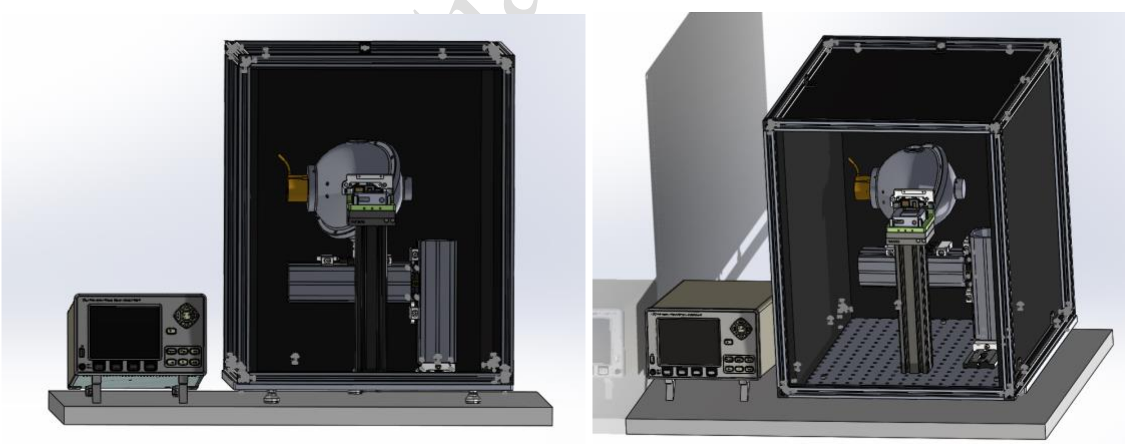

Figure 13: Optical power calibration station CAD

An example BOM for the ADI lab setup is shown in Table 3. The setup uses adjustable mechanical elements to accommodate alignment with different module designs. A production setup may not require the same level of adjustability. The integrating sphere and power meter solution is bandwidth limited so it effectively measures the average optical power envelope over an integration period. It does not have sufficient bandwidth to measure the peak optical power for each individual pulse but that can be characterized in advance along with measurement of the duty cycle. Alternative solutions to an integrating sphere that measures individual illumination pulses could also be considered.

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

Table 3: Optical power calibration example BOM

Note, the 2”x2”x10” mounting post requires four ¼”-20 taps for mounting the frame grabber kinematic base. As was the case for the lens focus frame, the cube connectors are optional, and brackets could be used to assemble the frame instead. The cube corner connectors are convenient for assembling the smaller calibration station frames but using them does add a requirement that the 20-2020 rails need an M5 tap at each end. This can be provided as a service from 80/20.net at additional cost and increased lead time.

ADI can provide LabVIEW and Python measurement and data collection code to control the instrumentation listed in the BOM above as reference.

The optical power calibration must be performed before P0 calibration as it may alter the phase measurements.

3.6 Phase Offset ("P0") Calibration

The P0 parameter is a frequency dependent phase delay that includes various delays both internal and external to the sensor itself. This phase delay must be calibrated for each pixel in order for the depth engine to provide an accurate depth measurement.

The 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. Every effort is made 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.

The P0 calibration station enclosure is approximately 0.5m x 0.5m x 0.5m.

The ADI P0 calibration station uses proprietary hardware and algorithms. ADI can provide executable code to perform the P0 calibration and can provide further hardware guidelines as required.

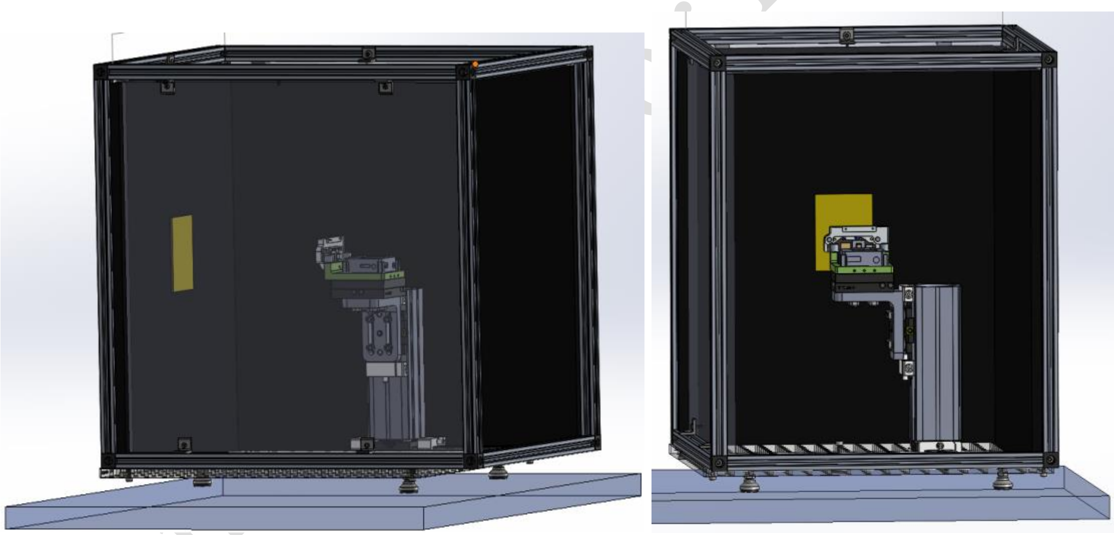

Figure 18. P0 calibration station CAD

The conceptual P0 calibration flow is shown in Figure 19. The P0 calibration is performed for all modes supported by the TOF camera module. The P0 correction table can be compressed to reduce the amount of stored calibration data.

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)
5. Use TestPhases data to extract the P0 Table, this is the P0 calibrated data to be compressed and stored in NVM.
6. From TestPhases frame data, apply the P0 Table to calculate the phases at each frequency supported by the mode.
7. Unwrap the radial distance
8. Repeat process, from step #2, for all implemented modes

The last two steps are for verification and data logging purposes

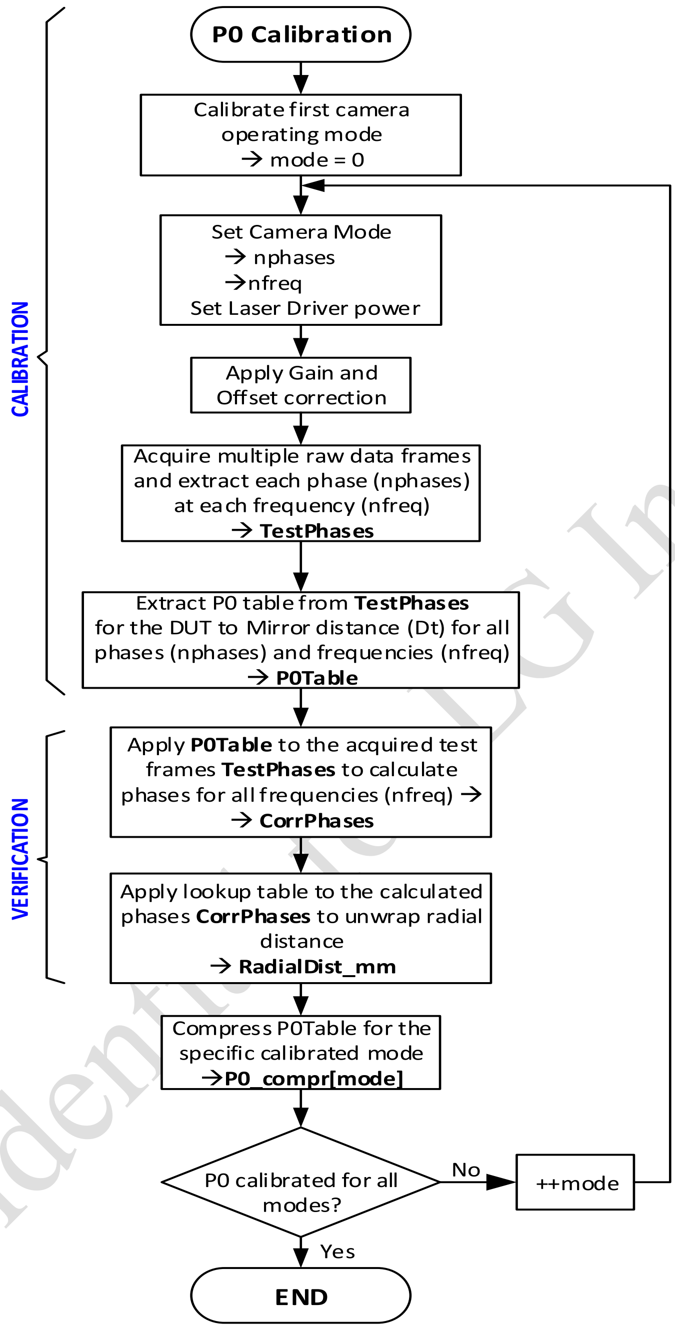

Figure 19: Generic P0 Calibration Flow

3.7 Beam Profile Check

The beam profile check is an important test to verify that the VCSEL/LD diffuser is operating correctly and to verify there are not any hotspots in the illumination profile. This is important because although the optical power station can be used to guarantee the maximum optical power levels match the programmed levels, if the diffuser is broken and all the illumination power is focused on a smaller than expected area then the eye safety limits could be exceeded. The beam profile check can be as simple as measuring the depth of a flat surface such as a wall with known reflectivity and verifying from the resulting captured active brightness images that the illumination profile and signal levels are as expected.

4 Optional Calibration Stations

The following calibration stations are not required to guarantee optimal ToF module operation but are useful to check for any potential quality issues.

4.1 Blemish Test

The blemish test is a test to check for any hot spots, dark pixels, or uniformity issues across the surface of the image sensor. The test can catch issues such as dust or other contamination on the image sensor and/or lens sub-assembly, manufacturing issues, or assembly issues.

The ADI lab setup uses an IR light panel which provides uniform illumination on the sensor. The light panel and camera/frame grabber are placed in a covered enclosure as shown in Figure 21.

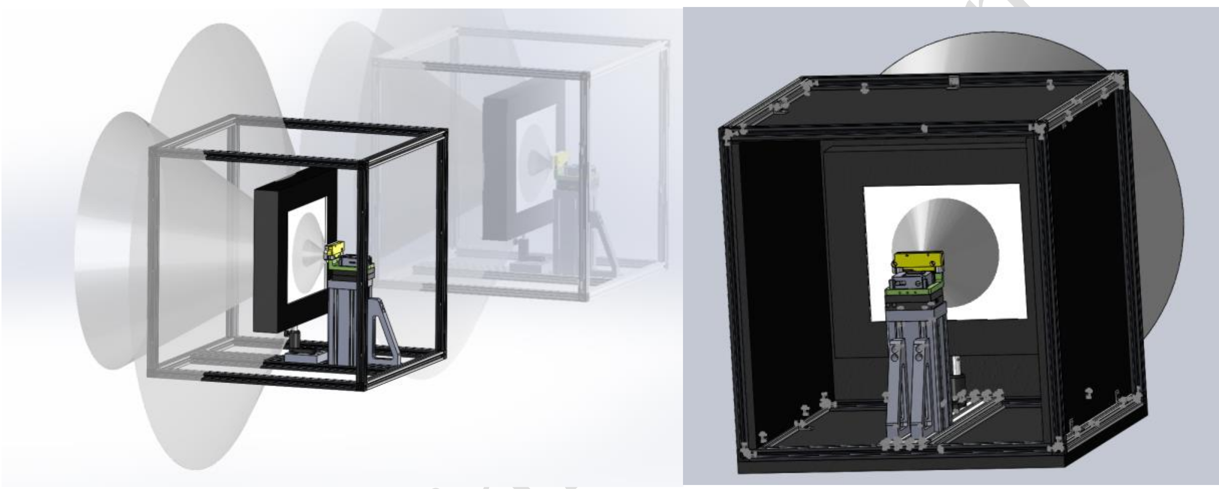

Figure 21: Blemish calibration station CAD

The ADI lab setup BOM is shown in Table 5. The setup uses an Imatest light panel (ILP-B) which has variable intensity from 2 to 20W/m^2 with 90% uniformity and can optionally be configured when ordering so it can operate at 850nm or 940nm.

The camera should be placed close to the light panel, so the panel covers the entire FOV of the camera.

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

Table 5: Blemish calibration station BOM

4.2 Final Check

The final check station can be used to verify that the depth measurements are reported correctly once all the calibration stages have been performed. Since the other calibration stages don't include any actual depth measurements, this can be a good quality check to verify the complete depth pipeline.

The ADI lab setup for the final check station consists of different targets at different known depths. This fixed scene can be used to functionally verify all camera modules. The drawback of this approach is that a large area is required to functionally verify depth measurements over the full depth of field of the camera. For space constrained production environments, another option could be to verify a few different depths in the FOV at the focus or geometric calibration stations.