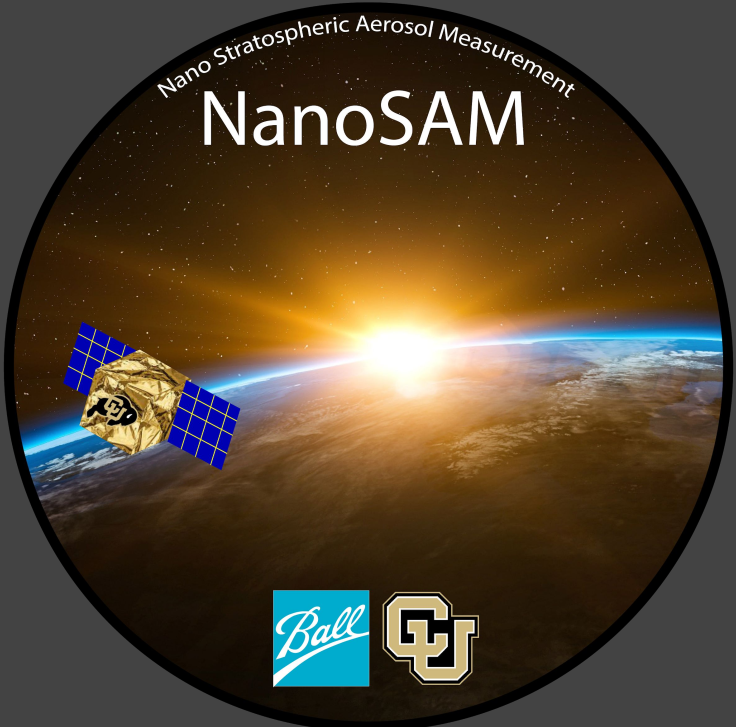

ASEN 4028 Senior Projects, Spring 2020
Test Readiness Review

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Conner McLeod, Aanshi Panchal, Jared Cantilina, Sara Reitz, Jacob Romero, Josh Horst

Customer: Jim Baer

Advisor: Dr. Zoltan Sternovsky

Agenda

Project Overview

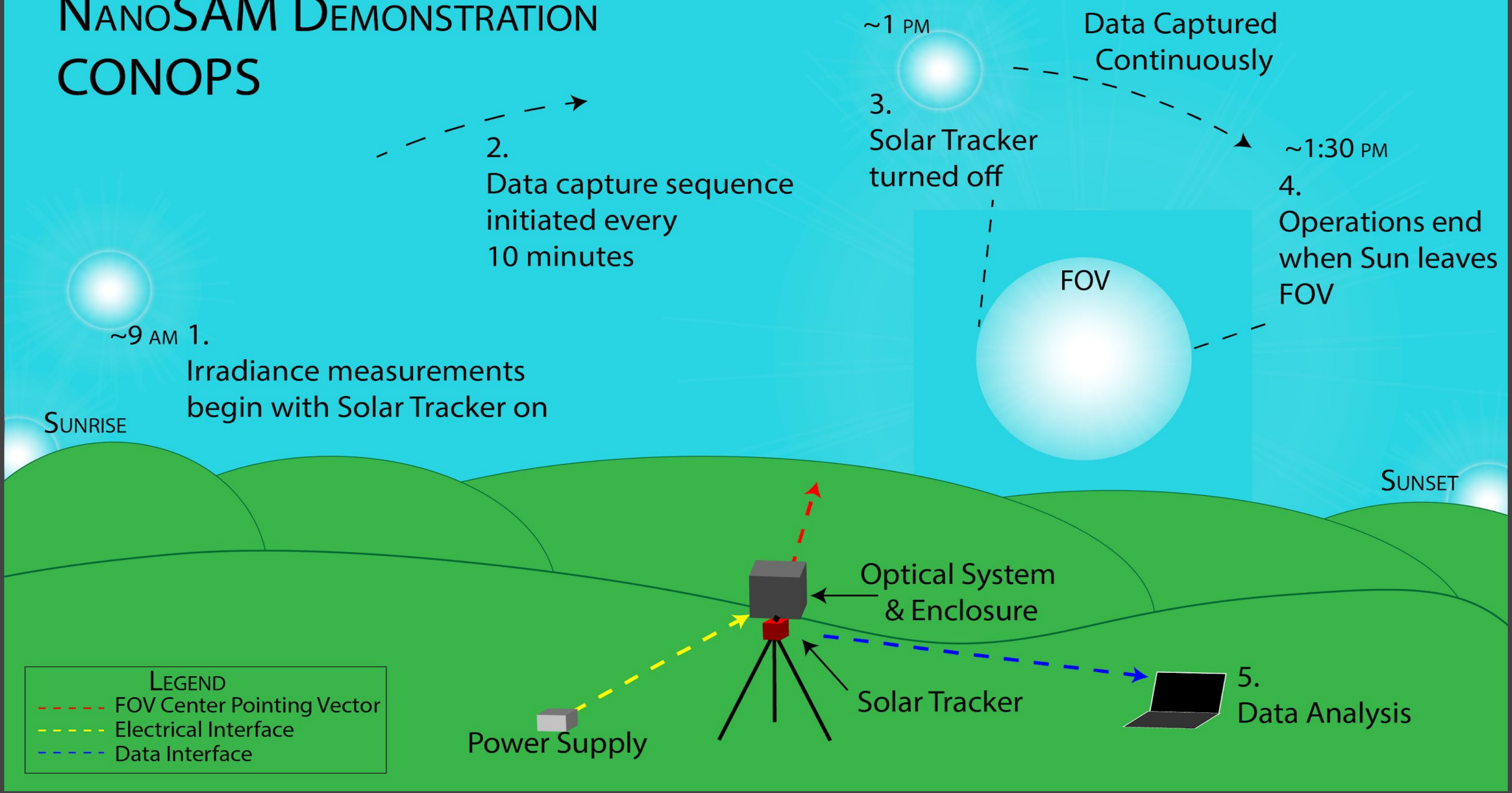
Project Statement

The NanoSAM team will collaborate with engineers at Ball Aerospace Corporation to design, construct, and test a functioning optics system that is capable of measuring solar irradiance in a narrow spectral band around 1.02 μm to obtain stratospheric aerosol concentrations data. An accompanying electronics system will also be produced for the purpose of collecting, packetizing, and outputting irradiance data.

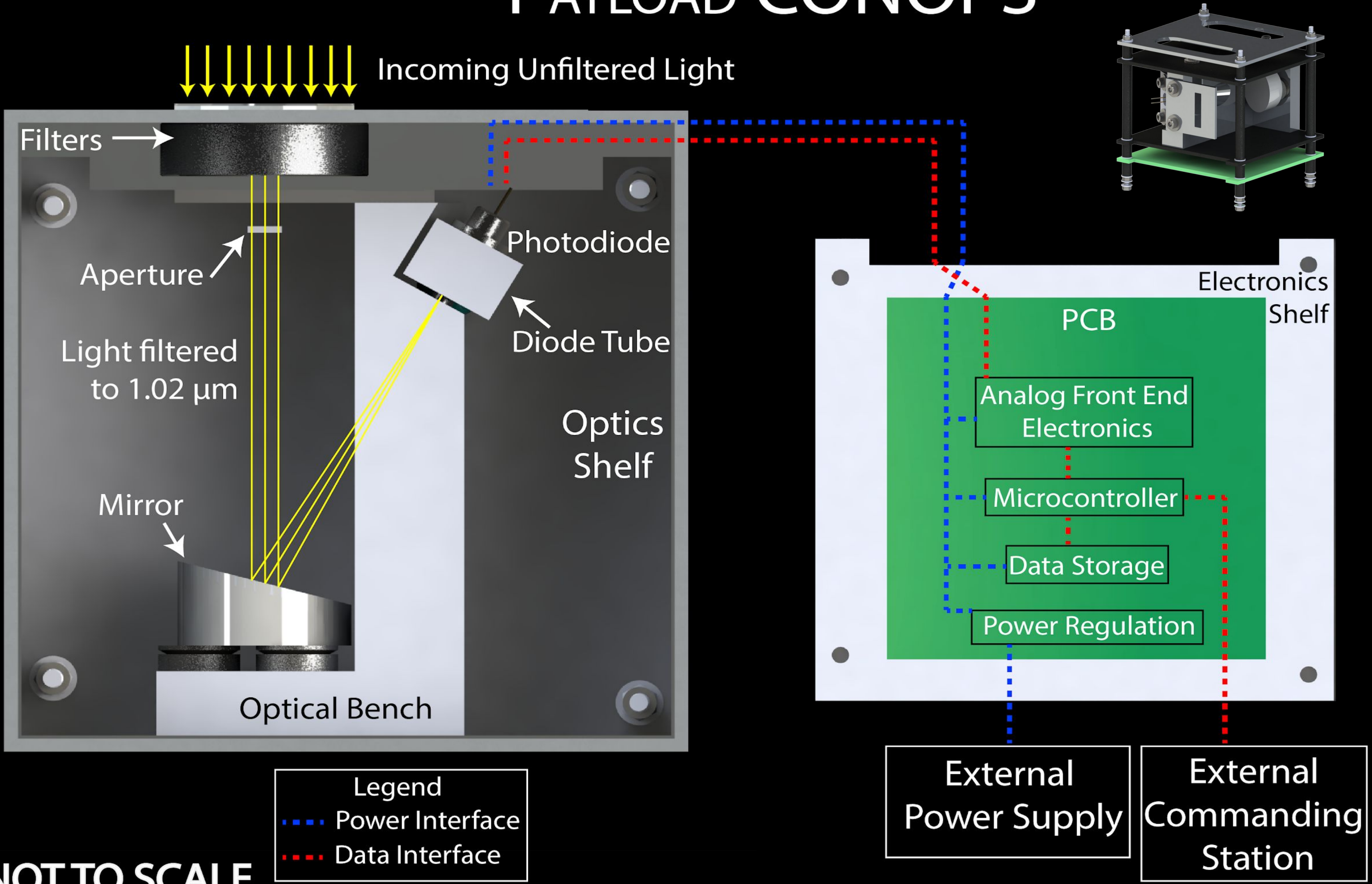
Specific Objectives

Objectives	Level 3
Solar Irradiance	Approx. linear irradiance data independent of temperature.
Instrument SNR	SNR ≥ 3500
Vertical Resolution	FOV facilitates 1km vertical resolution of atmosphere
Data Capture	Acquire, digitize, packetize, and download data from photodiode to computer. Incorporates synthetic data to simulate spacecraft health, slew rate, etc.
Payload Instrumentation Size	Radiometer & electronics compatible with 1U CubeSat footprint.
Mechanical Structure	All payload components secured to mock 1U CubeSat footprint

NanoSAM Demonstration CONOPS



Payload CONOPS

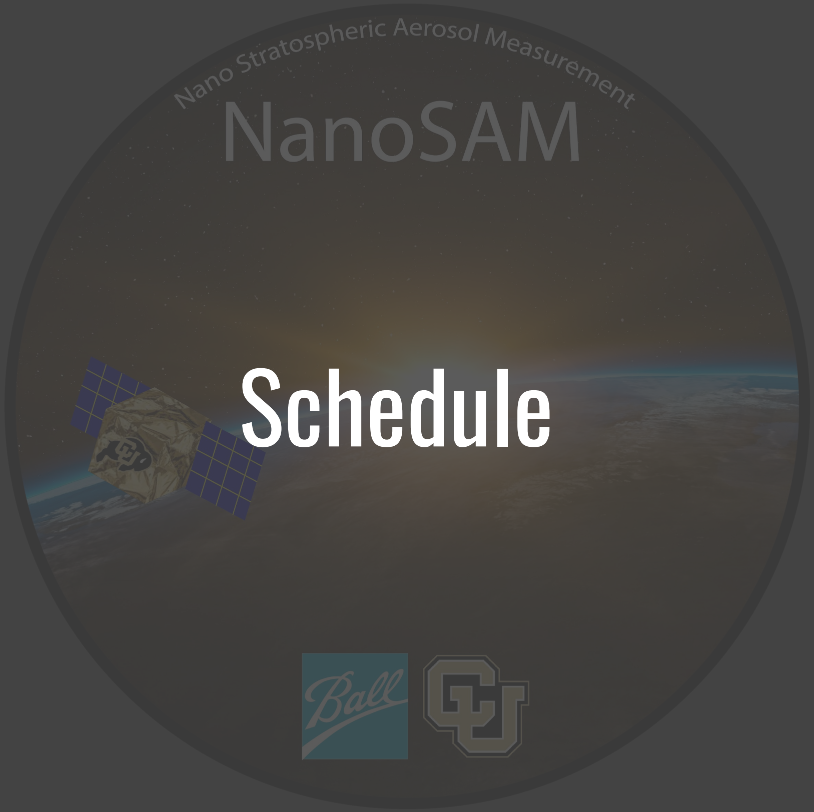


NOT TO SCALE

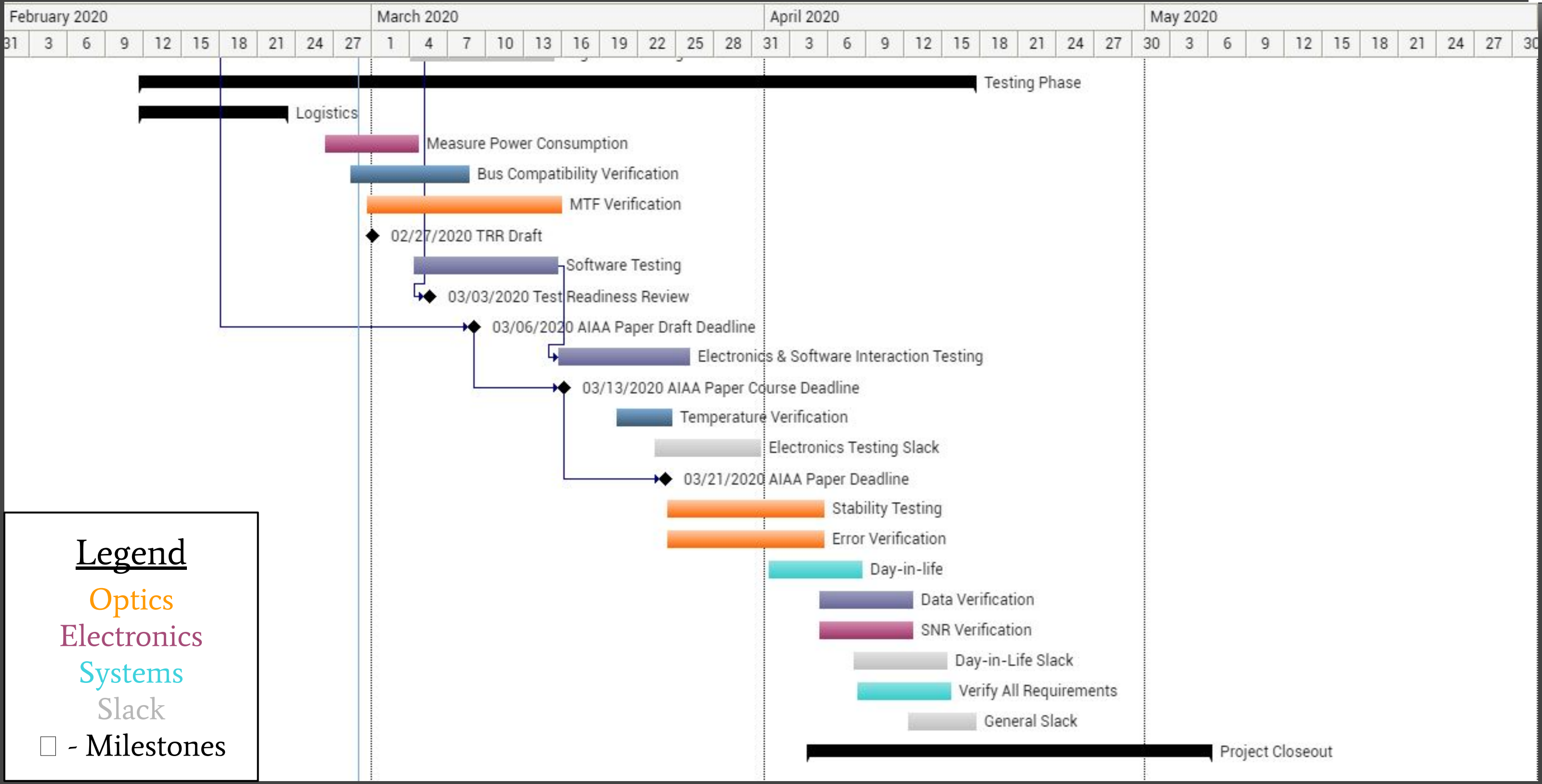
Critical Project Elements

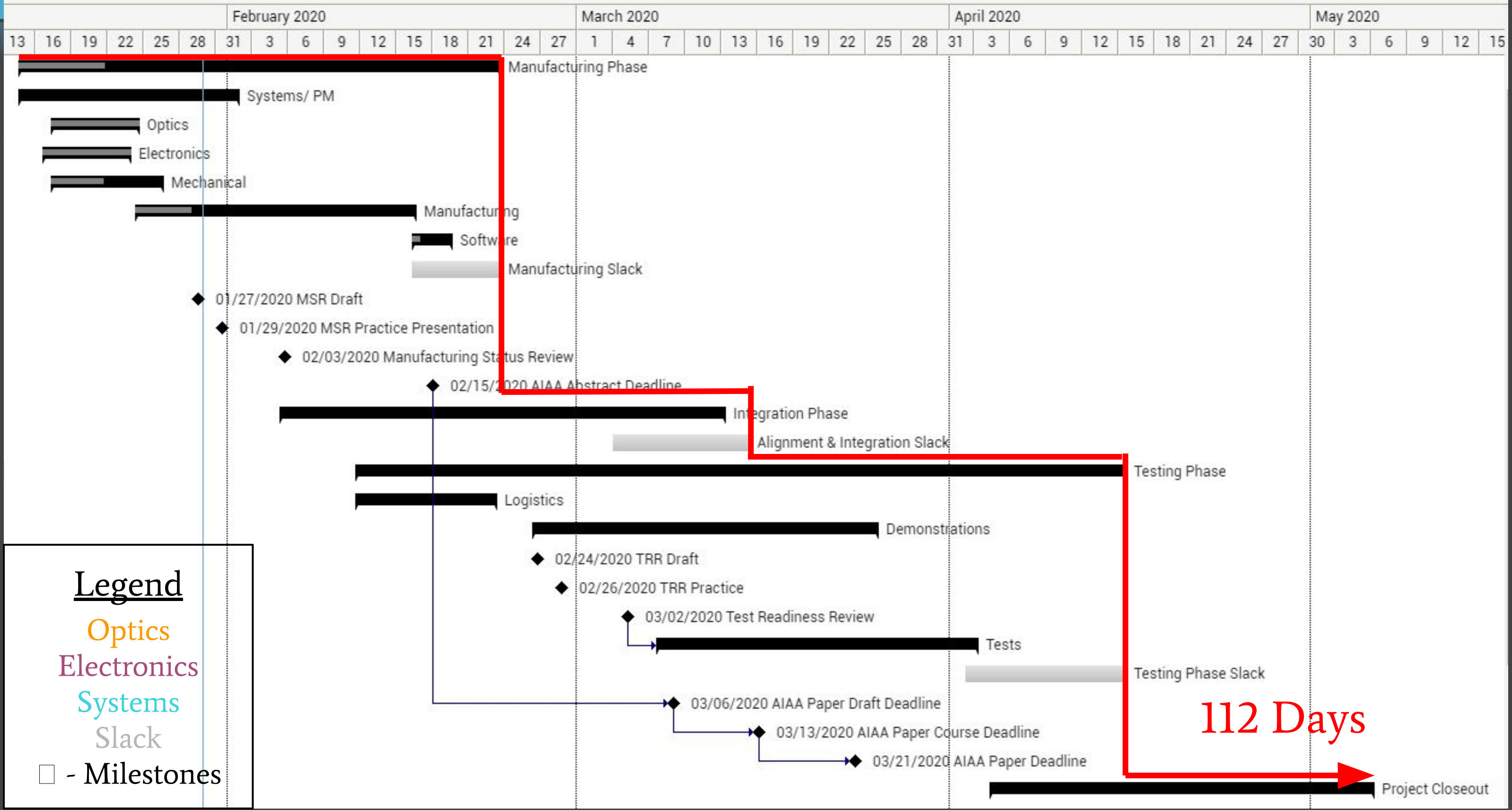
ID	Description
E.1	Radiometer detects solar irradiance in a narrow near-infrared band to measure atmospheric aerosol concentrations.
E.2	The instrument SNR and sample rate are the same as SAM-II or better.
E.3	The instrument field-of-view facilitates a vertical resolution of 1 km or less for the solar occultation method to perform as intended.
E.4	When the detector stays within its operating temperature, the baseline measurements remain stable over the duration of data collection for the collected data to remain accurate.
E.5	The optical instrument aligns with the pinhole field stop so that majority of the allotted wavelength of light can reach the detector for accurate measurements.

Schedule



Testing Phase





Legend

- Optics
- Electronics
- Systems
- Slack
- ☐ - Milestones

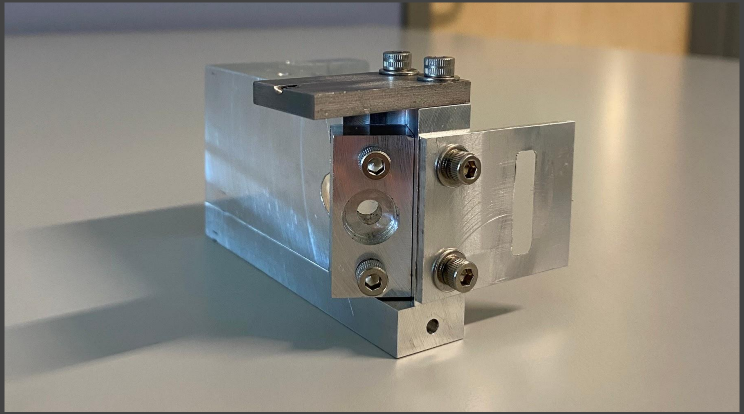
Critical Path

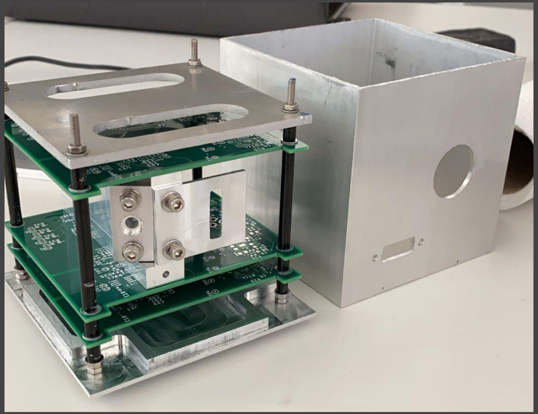
Test Readiness

Mechanical

Mechanical Tests Performed

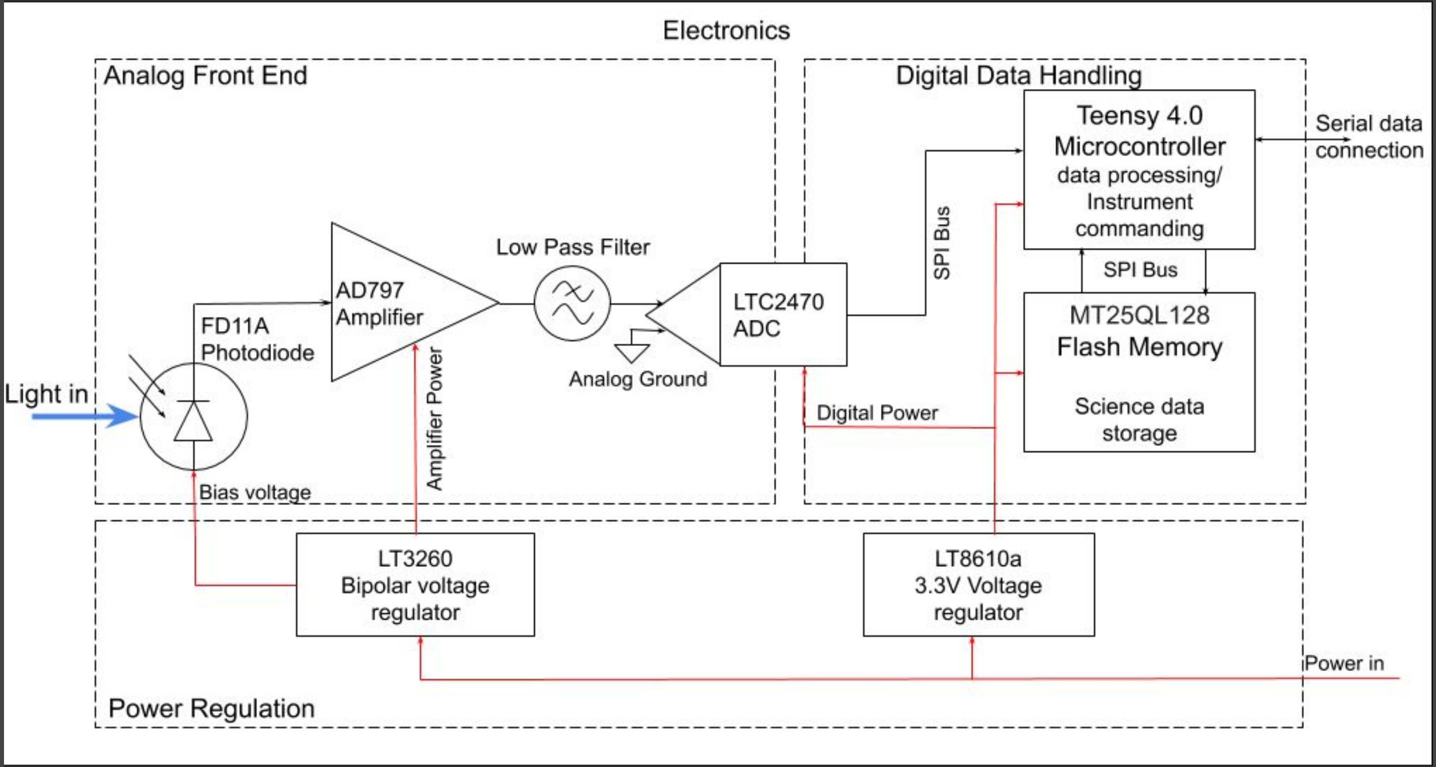
Test Performed	Relevant Requirement	Result
Mass of payload is less than 1.33 kg	2.2: Payload Mass	Success
Payload is removable from the enclosure	2.3.2: Removable Enclosure	Success





Electronics

Electronics FBD



Electronics Subsystem Tests Performed 1/2

FR 3.0: The electronics system of the payload shall be capable of collecting, packetizing, and outputting radiometry data.

Test Performed	Relevant Requirement	Result
Transimpedance amplifier converts current to voltage with expected gain	1.5: Dynamic range	Success
Noise in electronics is less than ADC's LSB	1.4: SNR	Success
ADC has at least 10 bits	3.1.2: Data Collection Bit Size	Success
ADC samples at 50Hz	3.1.1: Sampling Rate	Success
Microcontroller interfaces with a PC	3.3.1: Data Output Method	Success

Electronics Subsystems Test Performed 2/2

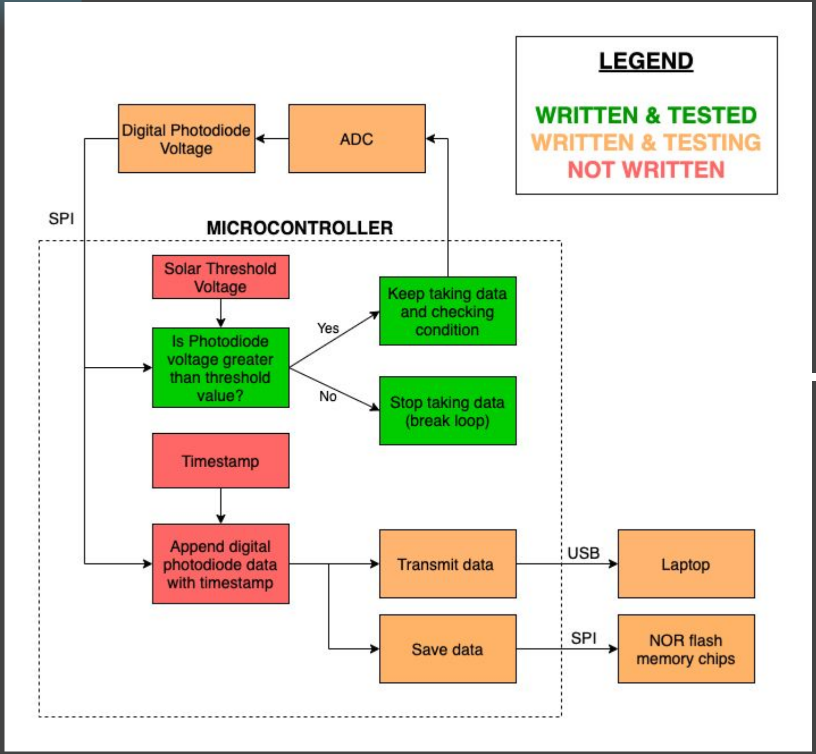
Test Performed	Requirement Verified	Result
Digital Power supply produces 3.3 V	3.0: Electronics System	Issue with buck converter IC. Using regulator on microcontroller instead
Microcontroller reads and writes at least 100Mb of data to flash	3.2.1: Data storage	Success
External ADC can read voltage from transimpedance amplifier	3.1: Data collection	Issue with PCB footprint. Using ADC on microcontroller instead
Analog Power Supply produces +/- 5V	3.0: Electronics System	Success

Electronics Subsystem Tests to be Performed

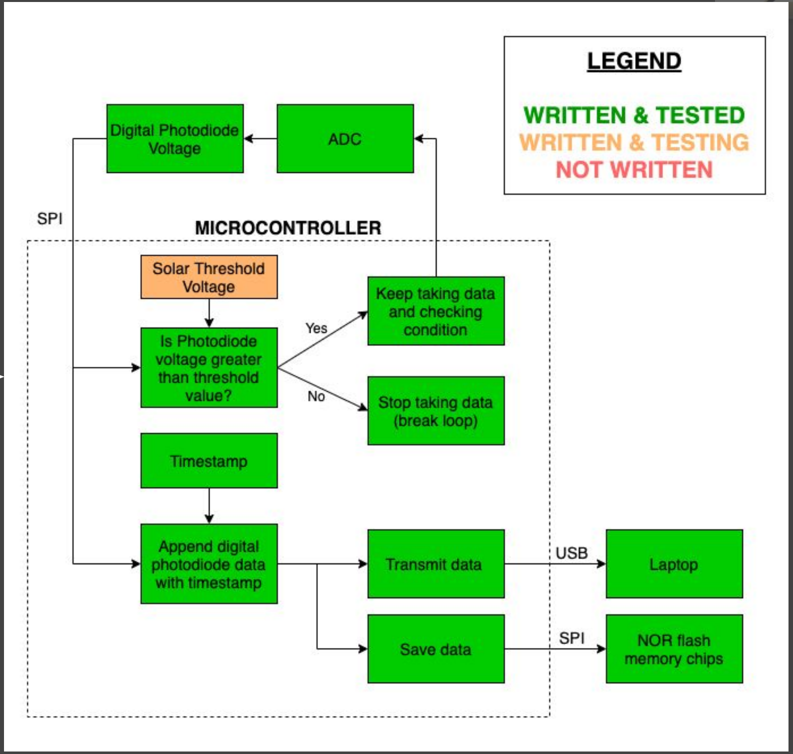
Test	Relevant Requirement	Date Planned	Support Equipment
Dark current measurement	1.4: SNR	Week of 03/09/20	Dark room or enclosure
Dark noise measurement	1.4: SNR	Week of 03/09/20	Dark room or enclosure
Measurement stability	1.3.1.1: Measurement stability	Week of 03/13/20	GND Filters, Calibrated Light Source
Saturation Test	1.5: Dynamic Range	Week of 04/01/20	Solar Tracker, integrated electronics, optics, and structure

Software

Software Progress



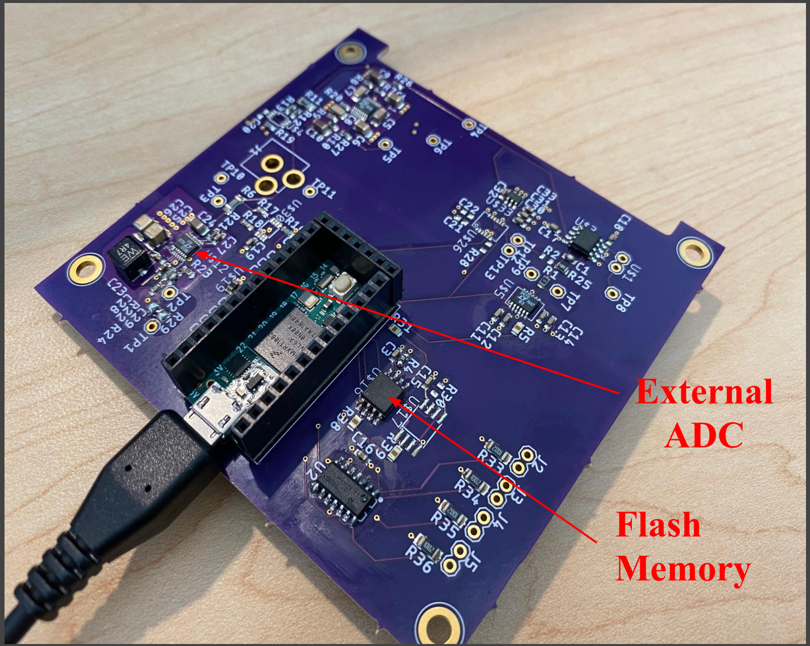
MSR



TRR

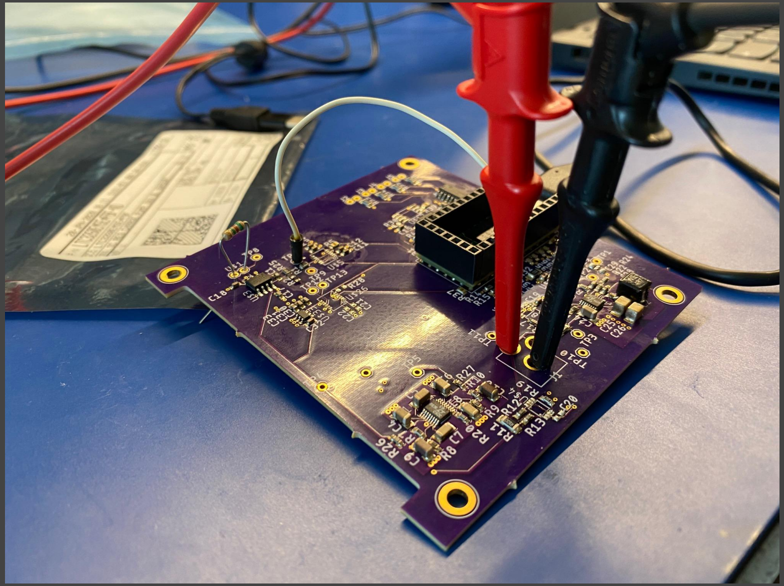
Hardware & Software Interaction Tests

Software Element	Status	Result
Write/read data to flash memory via SPI	Completed 2/15/20	Successful
Serial print data to laptop via USB	Completed 2/14/20	Successful
Receive data from external ADC via SPI	Completed 2/26/20	Could not read voltage from ADC
Create timestamp and append to data output	Completed 2/26/20	Success



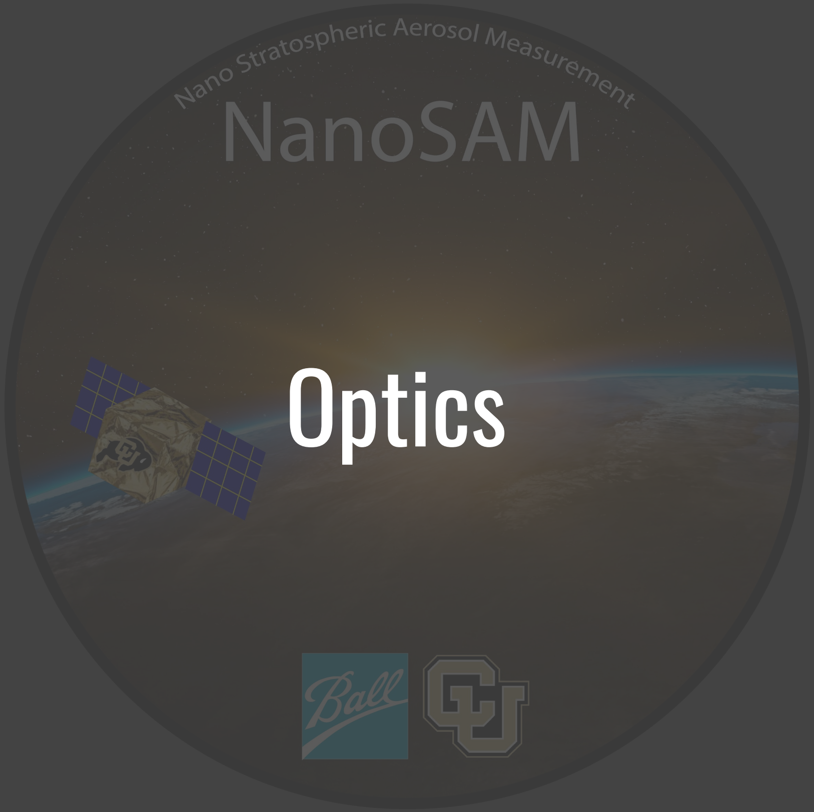
Software Tests to be Performed

Tests to be performed	Date Planned	Support Equipment
Integrated test with photodiode to estimate threshold voltage for data capture loop condition		



Testing software with powered PCB bypassing external ADC (2/26/20)

Optics



Optics Alignment Tests Performed 1/2

FR 1.0: The optical system of the payload shall be capable of collecting radiometry data.

Test	Status	Result
Req. 1.1.1: FOV 1.3 arcmins (or less) and 1 km Vertical Resolution	Completed Fall 2019	Successful
Optical Bench Integration	Completed 2/28/2020	The angle of the tooling plate screw is off. (Re-machining in progress)
Diode Block Integration	Completed 2/20/2020 2/28/2020	Successful Adjust pinhole handling and glue application

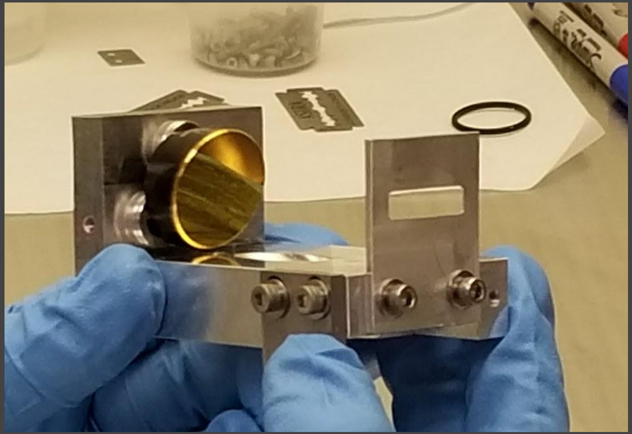
Optics Alignment Tests Performed 2/2

FR 1.0: The optical system of the payload shall be capable of collecting radiometry data.

Test	Status	Result
Optomechanical Mounting System	Completed 2/21/2020	Successful
Alignment Methodology with 50 μm Pinhole	Completed 2/28/2020	Not able to align to the pinhole during the scheduled lab session (not enough time).
Final Alignment of Optics System	3/6/2020	TBD

Optical Bench Integration

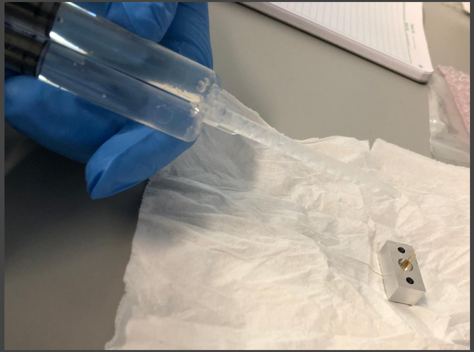
- Components and features tested:
  - Optical Bench
  - Aperture Stop
  - OAP Mirror
  - Diode Block
  - Precision Cut Optical Shims
  - Tooling Plate
- Component integration experience gained:
  - Working with shims is a lengthy process
    - Scheduling more lab time for alignment
  - Adding/removing shims requires removal of optical bench from mount
    - Additional optomechanics were added to preserve orientation of optical bench and allow for repeated removal

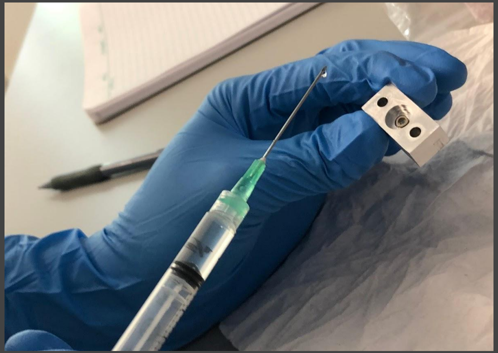


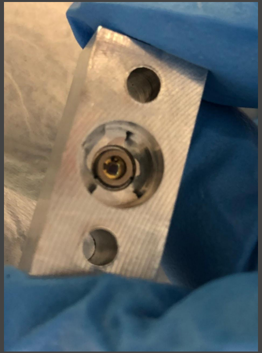
Diode Block Integration

- Components and features tested:
  - Diode press fit
  - Pinhole handling
  - Half sphere removal
- Component integration experience gained:
  - Glue application, Pinhole disk handling

Successful!
2/28/2020

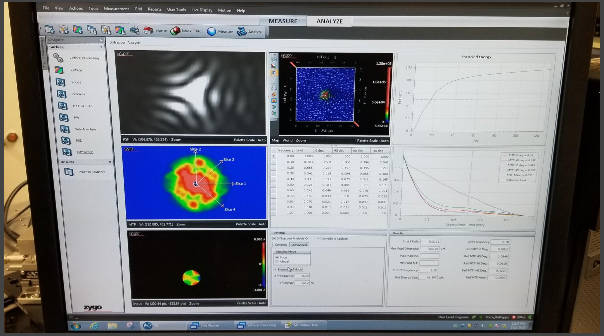






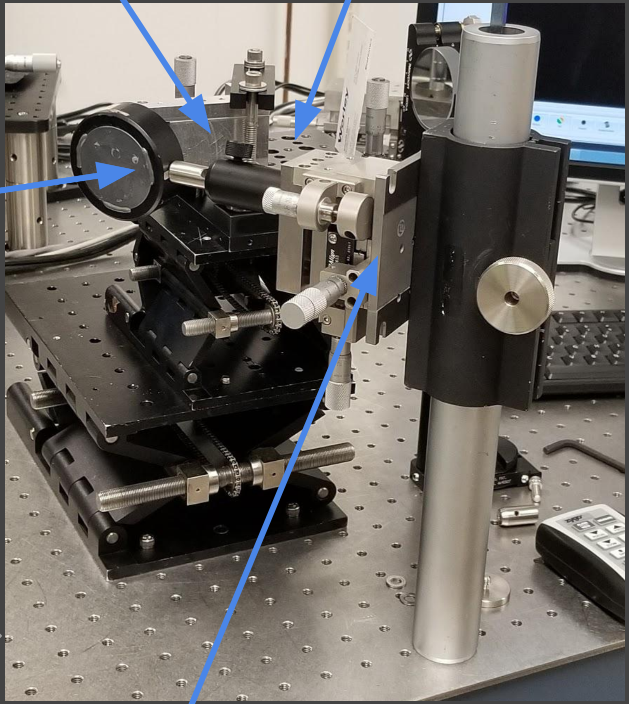
Alignment Facility & Optomechanics

- Zygo DynaFiz interferometer at Ball Aerospace
  - 4 alignment sessions with support of optical engineers
- Optomechanical mounting system
  - Platform height adjustment
  - 3-axis translation of return sphere
  - Tip-rotate stage for optical bench
  - 3-axis displacement of diode block (optical shims)

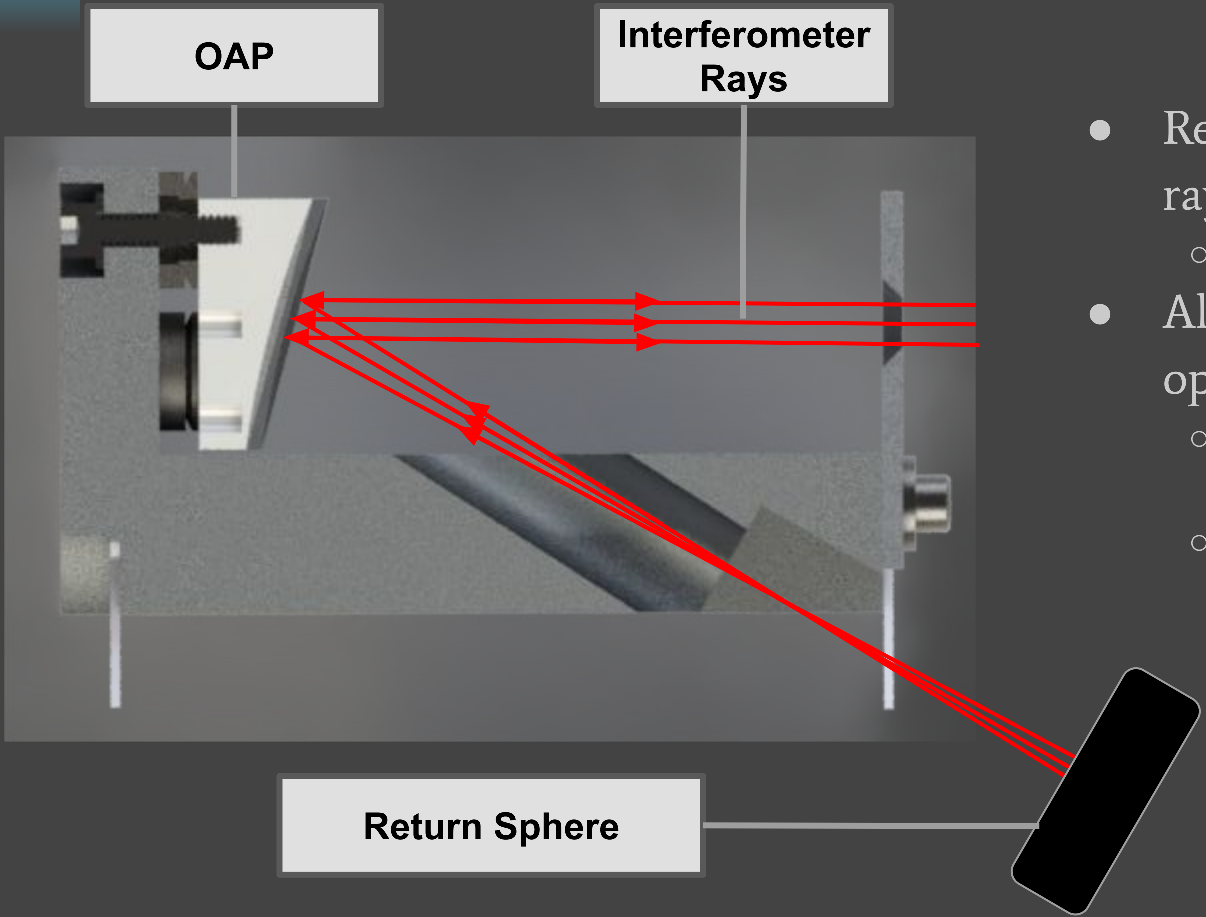


Interferometer software used to test alignment.

Mounts and platforms used to align the OAP mirror and interferometer.



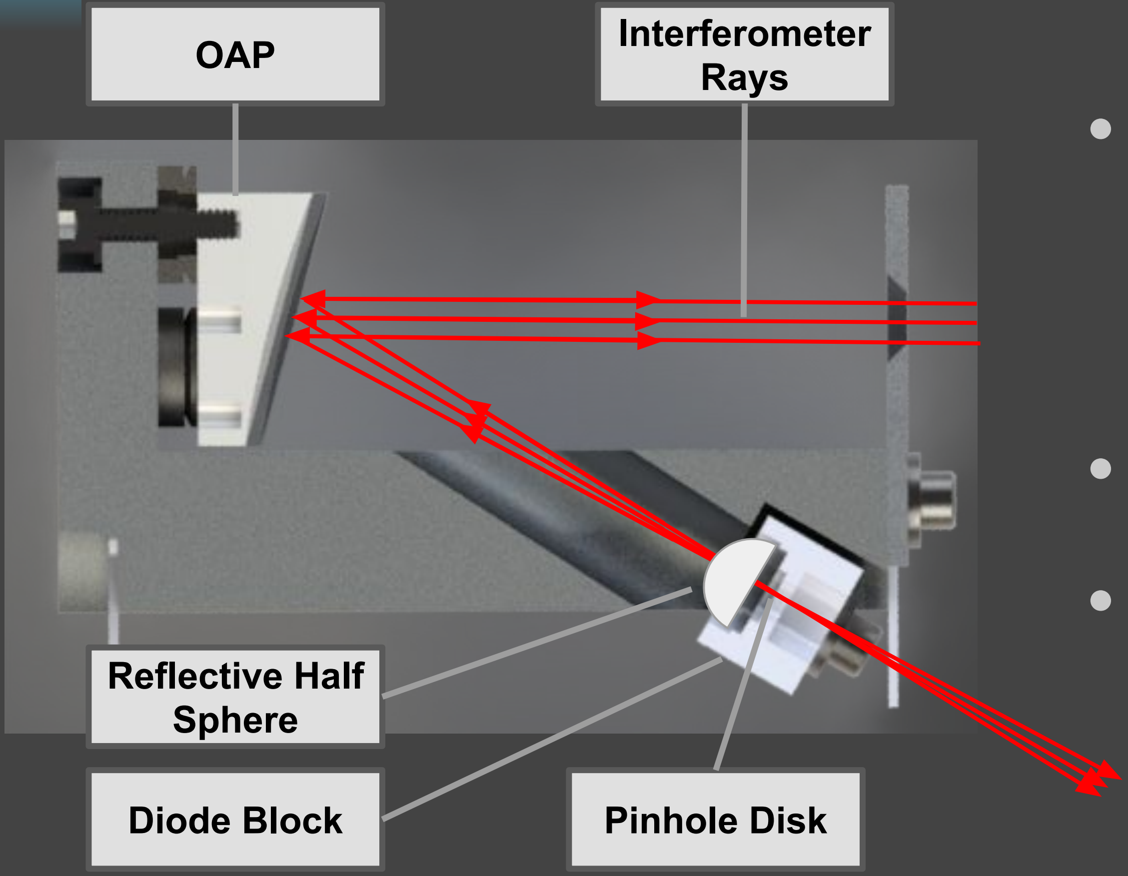
Interferometer-Mirror Alignment



- Return sphere used to return rays back through the system
  - Diode block not present
- Align interferometer rays to optimal axis of the OAP
  - Ensures pinhole is aligned to the optimal pointing direction
  - Highest possible MTF performance from mirror

Successful!
2/28/2020

Pinhole Alignment



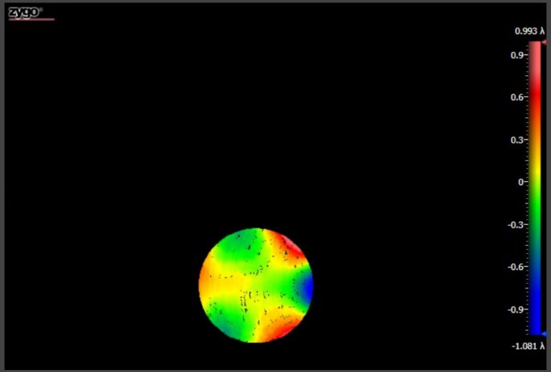
- Diode block and shims introduced
  - Begin with the nominal 1 mm shim stack
  - Add/remove shims until half sphere returns null fringe pattern
- Verify software MTF read out meets the requirement
- Remove half sphere and fine tune alignment using pinhole disk

Sessions scheduled next week

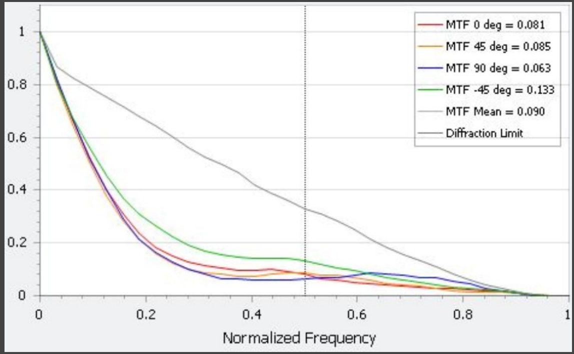
Optics Expected Results & Model Verification

- Preliminary test results indicate surface quality the OAP mirror is near manufacturers claimed performance
- MTF measured by DynaFiz interferometer compared to MTF predicted by Zemax

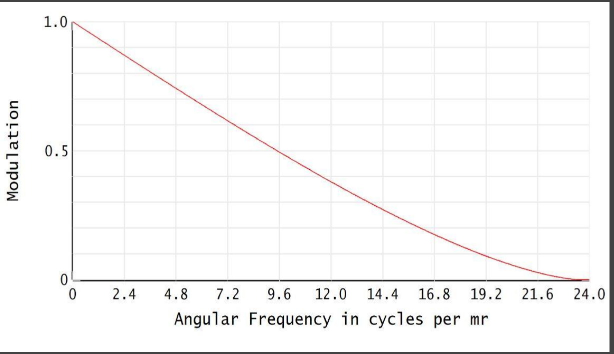
ZEMAX MTF Model Closely Approx. Interferometer Measurements



Left - OAP Wavefront Error



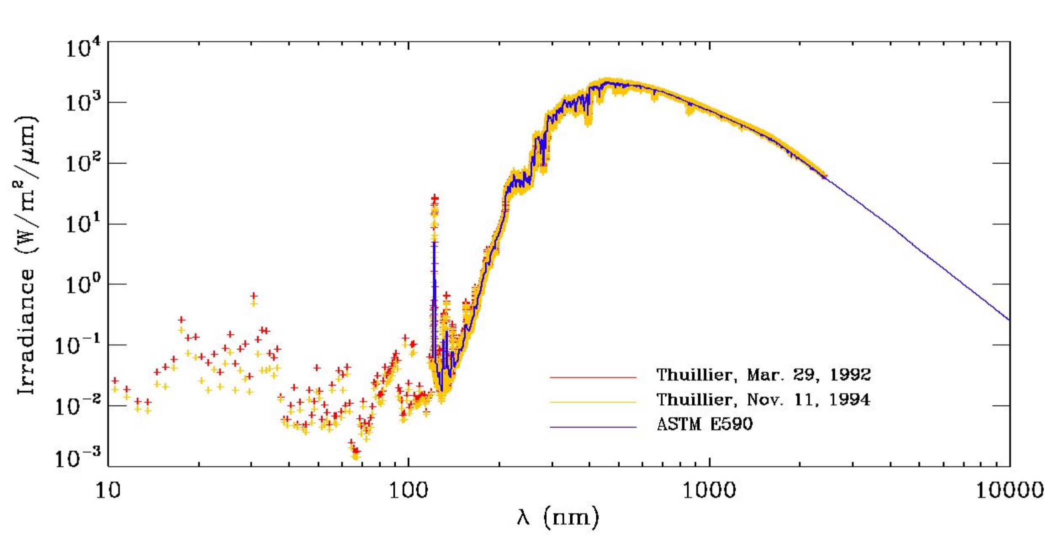
Center - Preliminary Test MTF Output



Right - Zemax MTF Comparison

Integration Testing

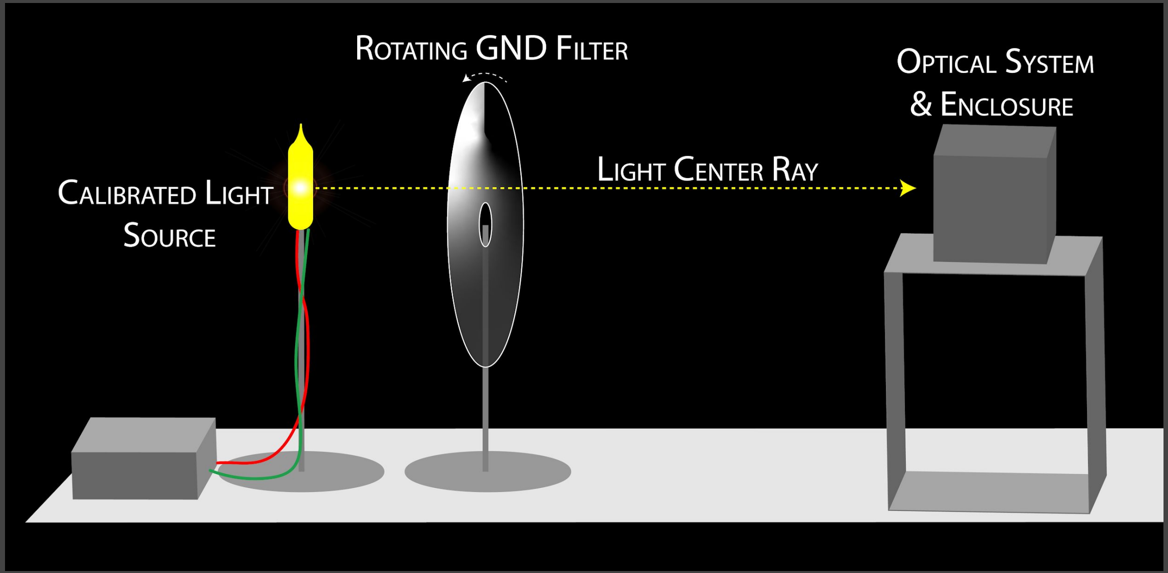
Spectral Irradiance



- Testing wavelength: 1020 nm
- Compare max value to literature
- Validate value with scientists

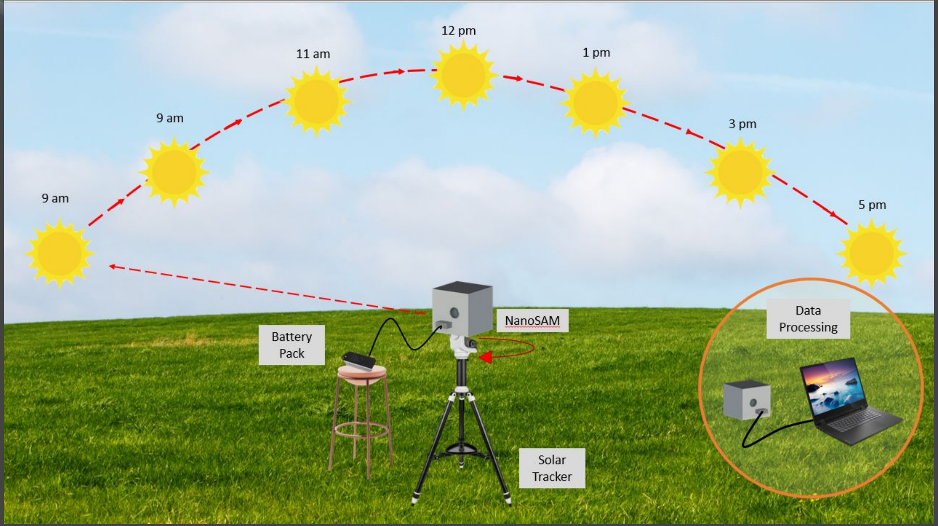
Verifies FR 1

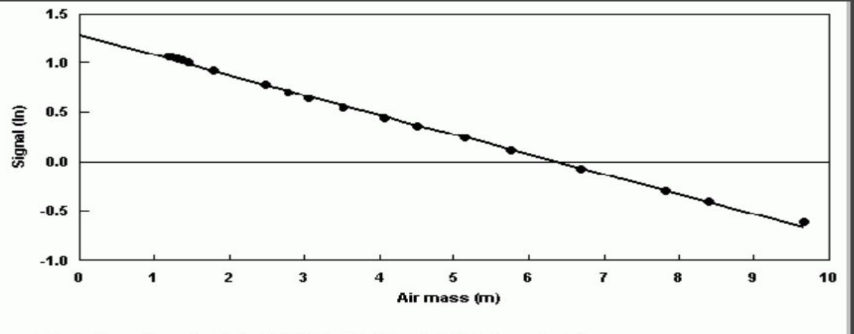
Reproducibility, SNR, & Temperature Verification



- Simulate attenuation of source signal
- Compare gathered data to expected results for multiple tests
- Check that data is stable over time and monitor the temperature of the system

Final Integration Testing

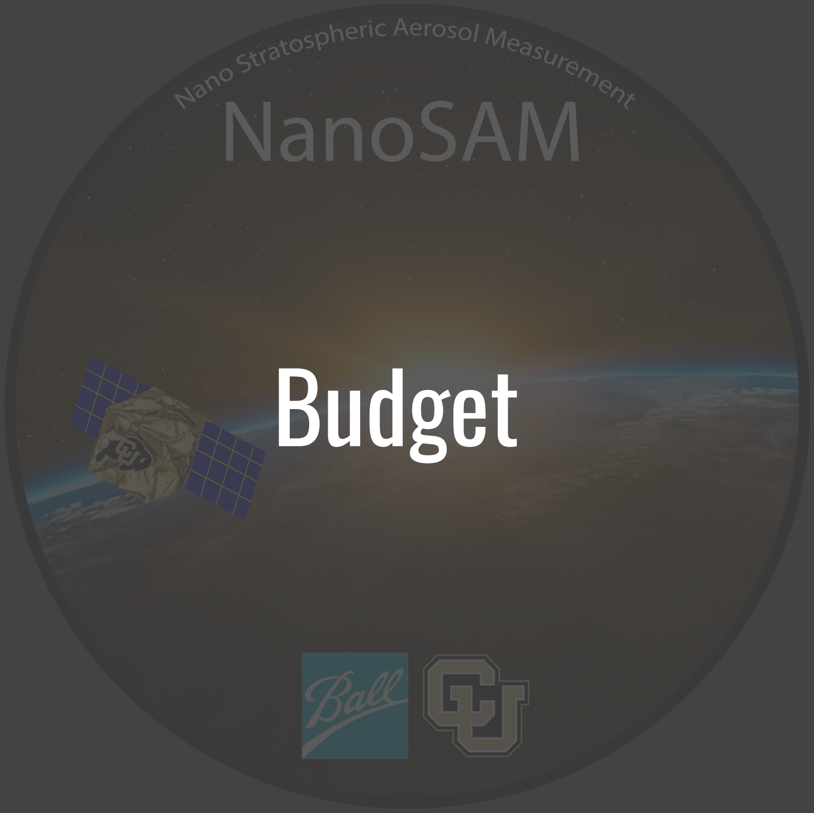




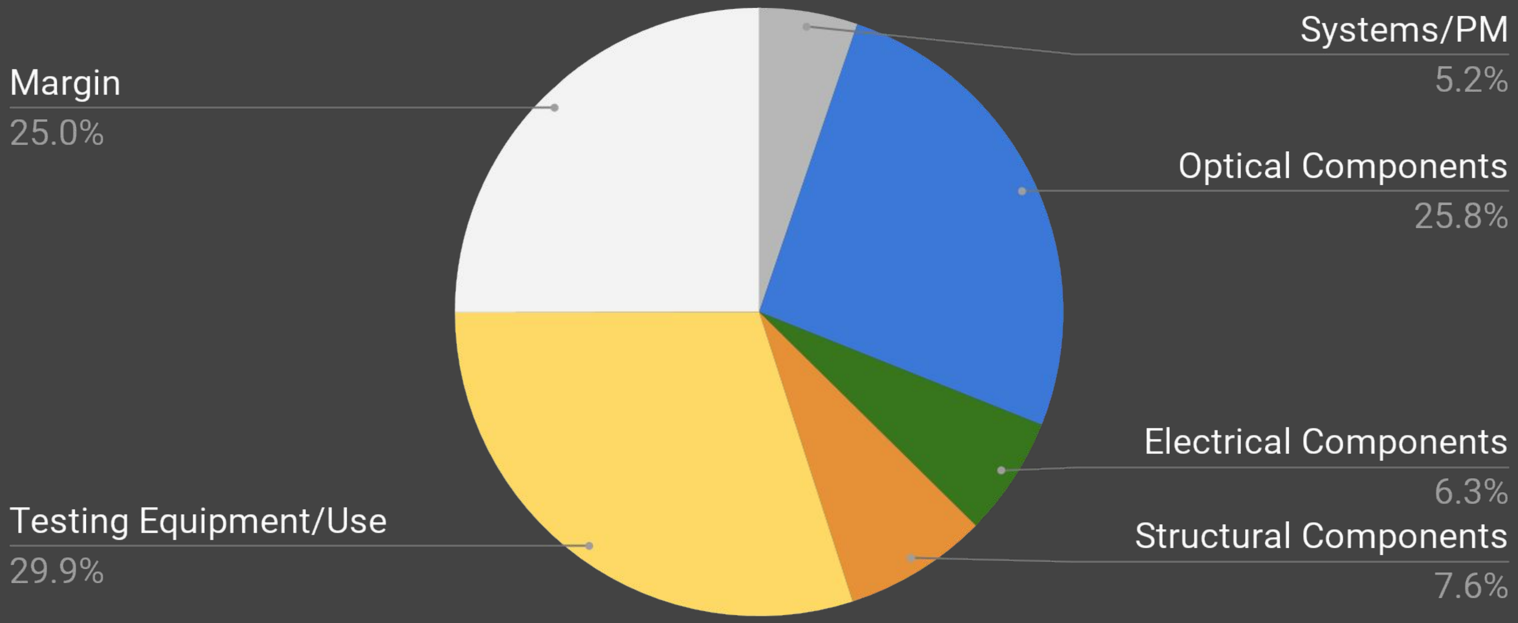
ıre 4. Langley plot of original VHS-1 (16 March 1996, Seguin, Texas).

- Perform test over multiple clear days
  - In front of AERO
- Mount NanoSAM on solar tracker & tripod
- Powered by battery pack
- Turn off solar tracker after solar noon
- Data downloaded to laptop for post-processing
- Use Langley extrapolation method to determine irradiance for zero air mass
- Use 1st test to determine threshold voltage for data capture loop condition

Budget

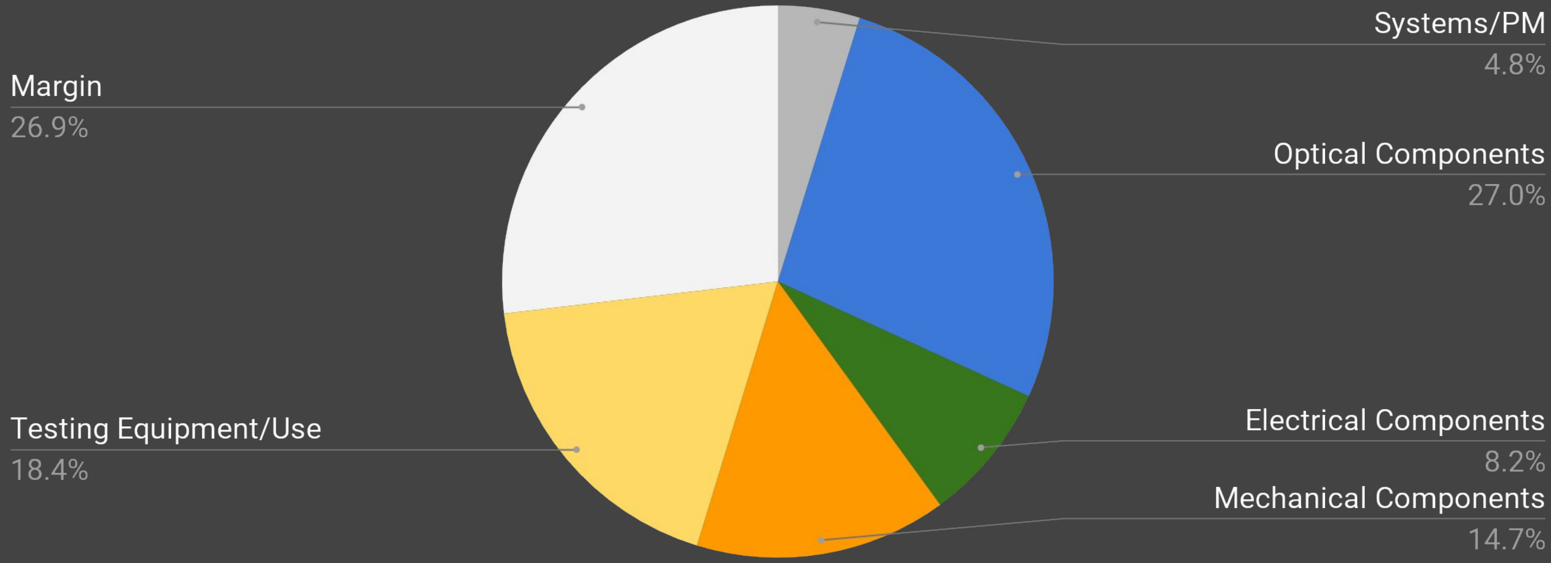


Predicted Cost Plan



Balance: $3,755
Available Budget: $1,245

Updated Cost Plan



Balance: $3,657
Margin: $1,343

Testing budget decreased
Mechanical budget increased

Conclusion

Volume, Mass, and Portability Requirements of the Instrument and Enclosure have been Verified

PCB Populated and Components Tested - Microcontroller Taking on Additional Tasks

Software Testing Ongoing - Working on Threshold Voltage and Data Packetization Codes

Optical Alignment in Progress - OAP Aligned to Interferometer - Shimming Continuing this Week

Acknowledgements

Jim Baer - Ball Aerospace Corp

Joe Lopez - Ball Aerospace Corp

Dr. Cora Randall - LASP

Matt Rhode - CU Boulder

Zoltan Sternovsky - CU Boulder

Haley Knapp - Ball Aerospace Corp

Resources

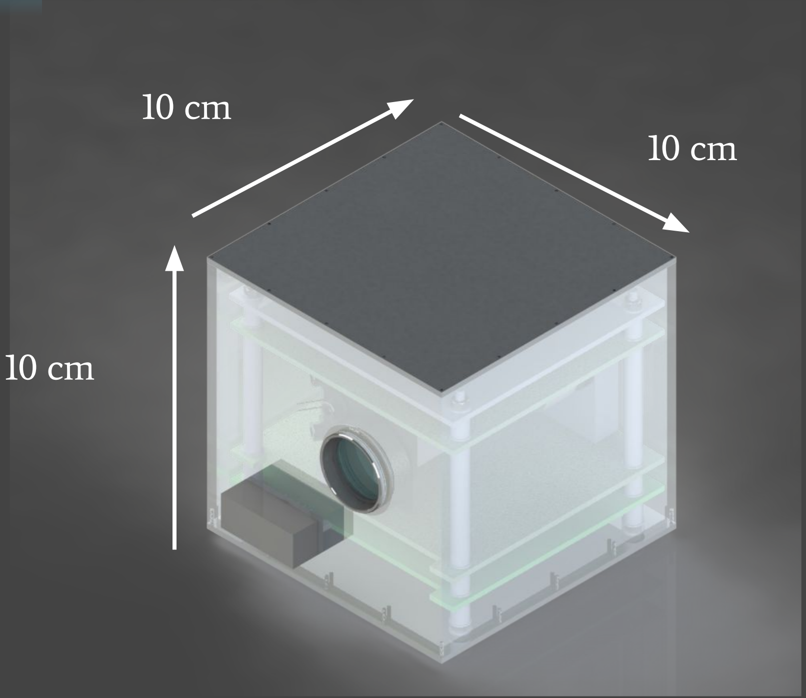
- https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=10773
- http://www.mpia.de/~mathar/public/mathar20151213.pdf
- https://www.atmos-meas-tech.net/9/215/2016/amt-9-215-2016.pdf
- https://www.edmundoptics.com/?gclid=EAIaIQobChMIn6yV7fuZ5QIV9yCtBh34GwFBEAAYASAAEgLHv_D_BwE
- Sigma Delta ADC Datasheet
- AD8012 Transimpedance Amplifier Datasheet
- FD11A Si Photodiode Datasheet
- http://www.cubesat.org/
- “15 Wave-Front Aberrations and MTF.” *Modern Optical Engineering: the Design of Optical Systems*, by Warren J. Smith, 4th ed., McGraw Hill, 2008.
- “Chapter 11 Transfer Functions; Hubble Space Telescope.” *Astronomical Optics*, by Daniel J. Schroeder, 2nd ed., Academic Press, 2000.
- “CHAPTER 1 MTF IN OPTICAL SYSTEMS.” *Modulation Transfer Function in Optical and Electro-Optical Systems*, by Glenn D. Boreman, vol. TT52, SPIE Press, 2001.
- POAM III retrieval algorithm and error analysis (SNR value)
- https://www.nasa.gov/mission_pages/sdo/science/solar-irradiance.html
- https://www.ioccg.org/groups/Thuillier.pdf

Backup Slides

Table of Contents

Mechanical

Structural Design Overview

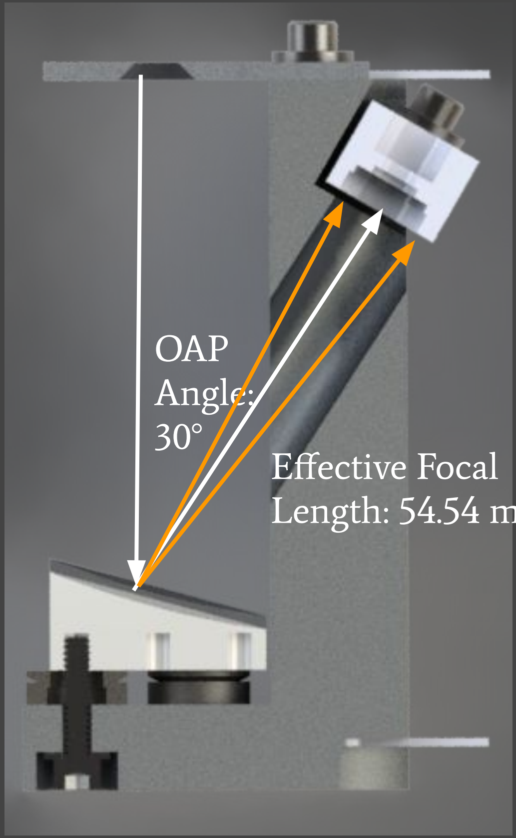


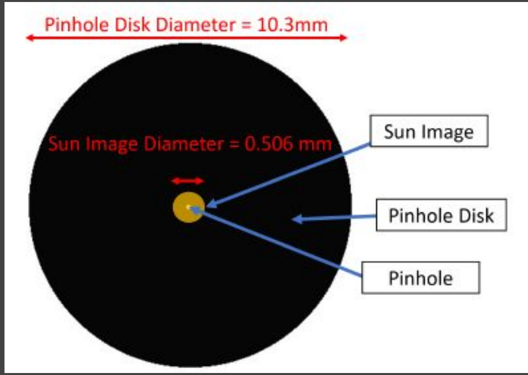
- Sealed enclosure
- Exterior electronics port
- Threaded filter mount

Mass: 1094 g
Volume: 1000 cm^3

Satisfies Functional RQMT 2

Mechanical Geometric Design and Tolerances





Pinhole Diameter: 0.015 mm

- Available movement of light from nominal distance: (.506/2) - (.015)/2 = 0.2455 mm
- Allowed deviation in angle: ΔΘ = arctan(0.2455/54.54) = 0.5752818° from nominal angle of OAP
- Therefore, the "L" on the optical bench must be 90° ± 0.5752818° as a cumulative error
- We can get accurate within 2 orders of magnitude more in the AERO Machine shop - feasible
- Ale to test this with either measurement tools or alignment with our interferometer & Zernike Coefficients

UNC 6 AL6061-T6 Bolts

UNC 6 Bolt

- 5.3 in-lbs torque
- 0.0001 in elongation of diameter for +20K temperature change

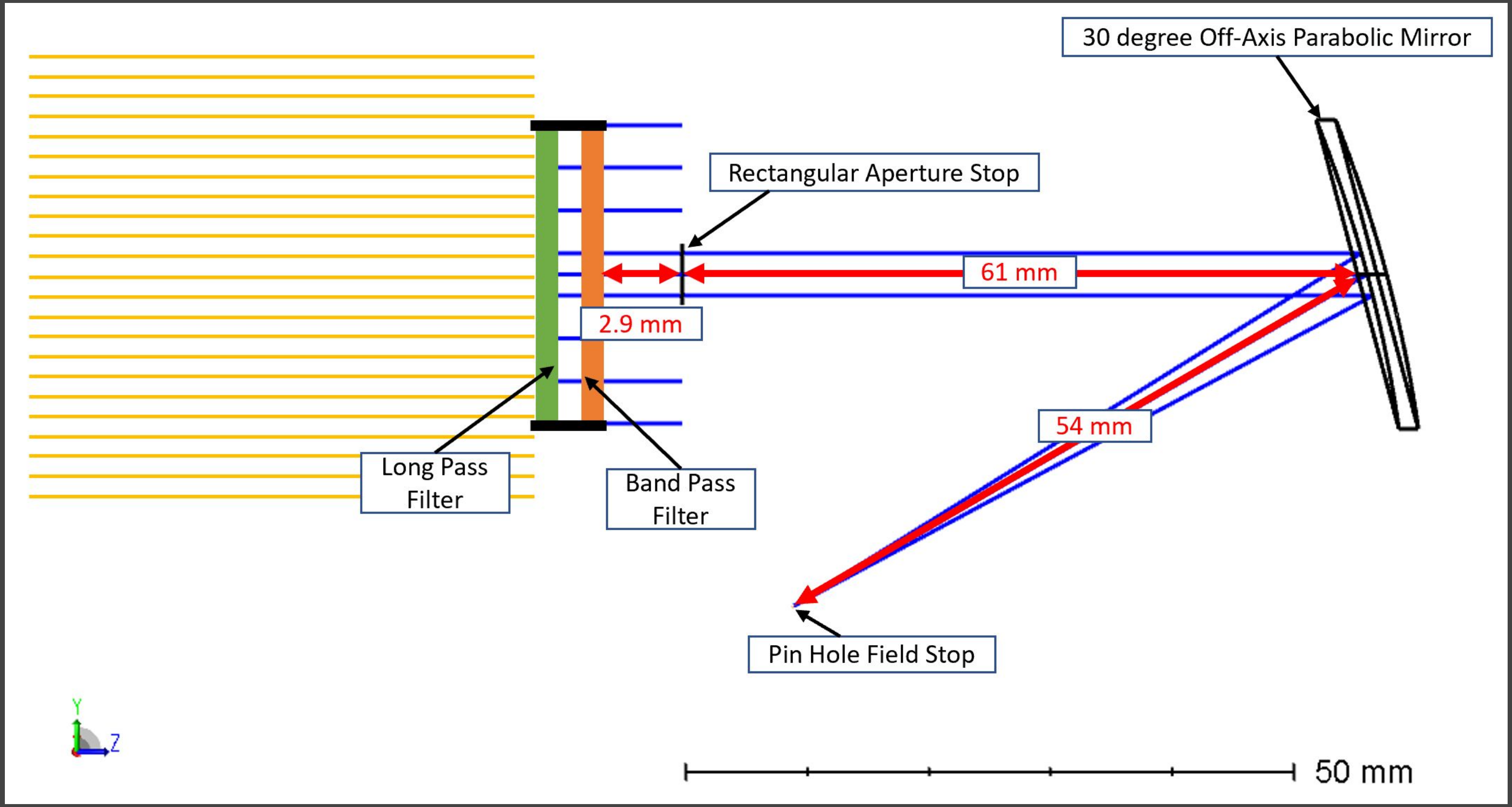
Optics

Optical Bench: Preliminary Geometric Tolerance

Geometric Tolerance Stack Up			
	Image X [± mm]	Inage Y [± mm]	Image Z [± mm]
Spherical Whashers	0.127	0.127	0.127
Mirror Width	0.127	0.127	0.127
Bench Back Plate	0.127	0.127	0.127
Bench Base Plate	0.127	0.127	0.127
Mirror Bolt Holes	0.227	0.227	0.227
Shim Faces	0.127	0.127	0.127
Diode Tube Faces	0.127	0.127	0.127
Diode Tube Half Sphere Slot	0.127	0.127	0.127
Sum:	1.116	1.116	1.116

- For CNC mill tolerance of 5 mils
- Nominal Shim Stack 1.5 mm
- Tolerances
  - Worst case image plane contributions used
- Allowable angle deviation of the mirror: .4 degrees

Optical Design Overview



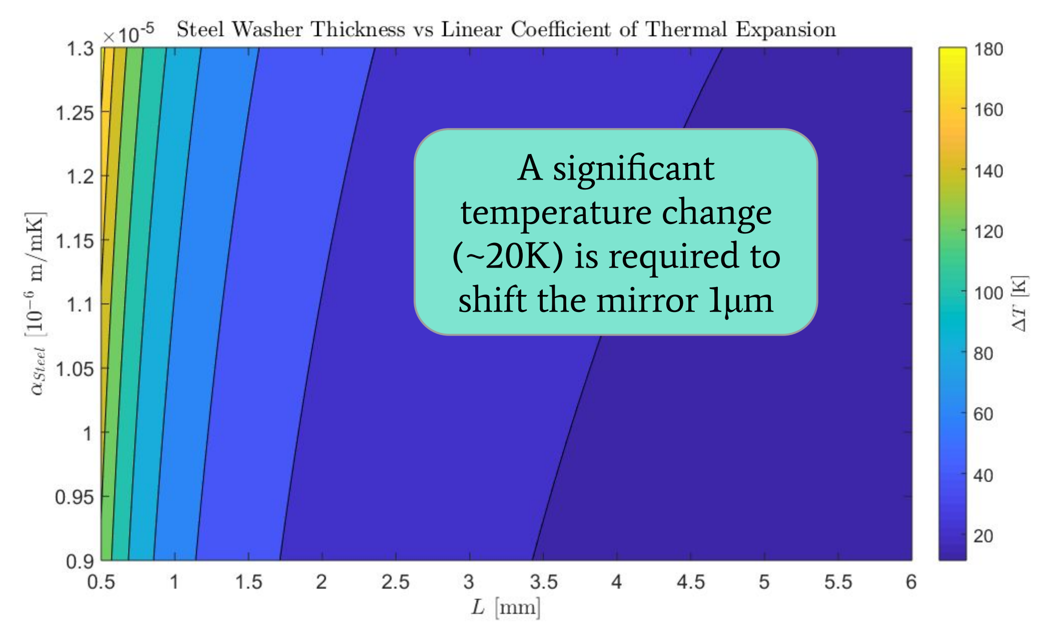
ZEMAX OpticStudio Model diagram

Other Factors Degrading MTF

- MTF Losses of NanoSAM
  - lambda /4 SFE for 30 deg off axis parabolic mirror ~ 80% degradation
  - lambda/8 WFE for both long pass and band pass filter ~ 50% degradation
  - -XX% margin
- MTF Losses of Flight Ready NanoSAM
  - lambda/16 SFE custom off-axis mirror ~ 10% degradation
  - lambda/? WFE for both long pass and band pass filter ~ XX% degradation
  - +XX% margin
- NanoSAM will not meet MTF requirement due to mirror and filter irregularities however given a better mirror and filter the MTF requirement can be met

Thermal Effects on MTF

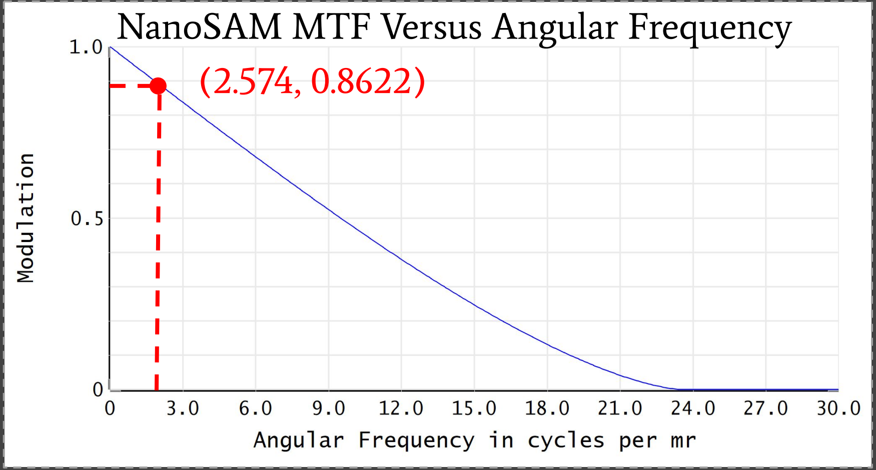
- Thermal expansion can shift the mirror with respect to other aluminum components
- Shifting the mirror is equivalent to shifting the pinhole
- Athermal system is composed of a single material
- Thermal expansion of steel washers is different than the thermal expansion of the Al-6061 components



Note: The plot shows the required ΔT for a 1μm difference in the thermal expansion for steel washers for a given coefficient of thermal expansion.

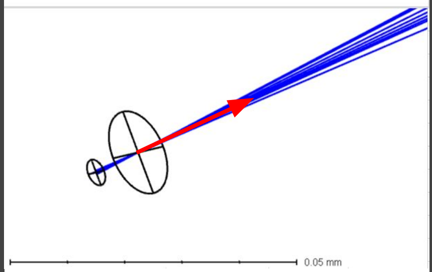
Pinhole Alignment and Allowable Error

- MTF Analysis
  - NanoSAM Diffraction Limited MTF = 0.8622, ν = 2.574 [cycles/mrad] (Zemax)
  - SAM Diffraction Limited MTF = 0.74
    - NanoSAM MTF should not degrade below 85.6 percent from 100 percent in order to meet or exceed SAM performance



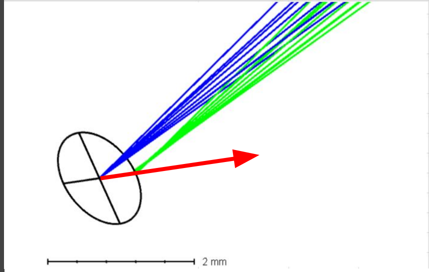
Satisfies MTF Requirement

Pinhole Alignment and Allowable Error



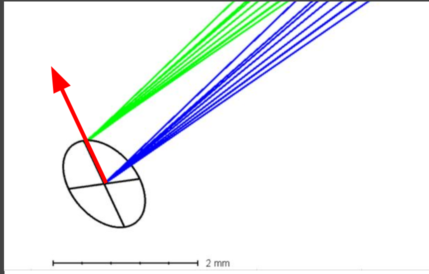
+Defocus

Displacement Range: ±138 μm



+Image Plane x-axis

Displacement Range: ±138 μm



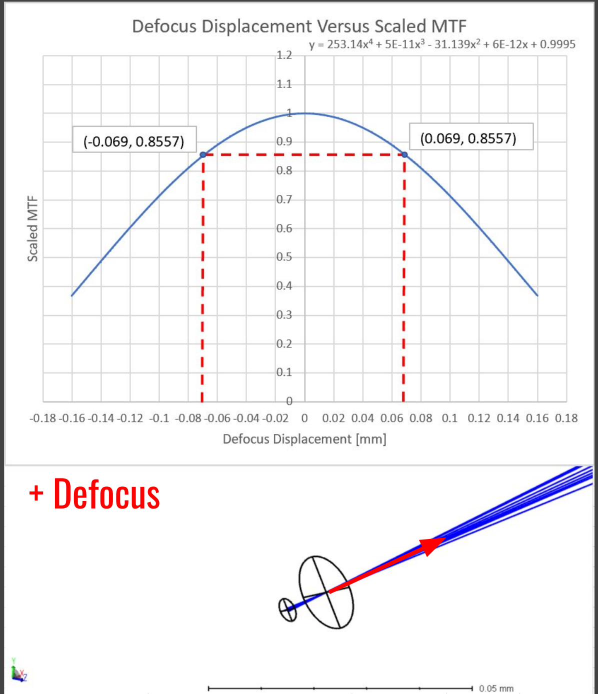
+Image Plane y-axis

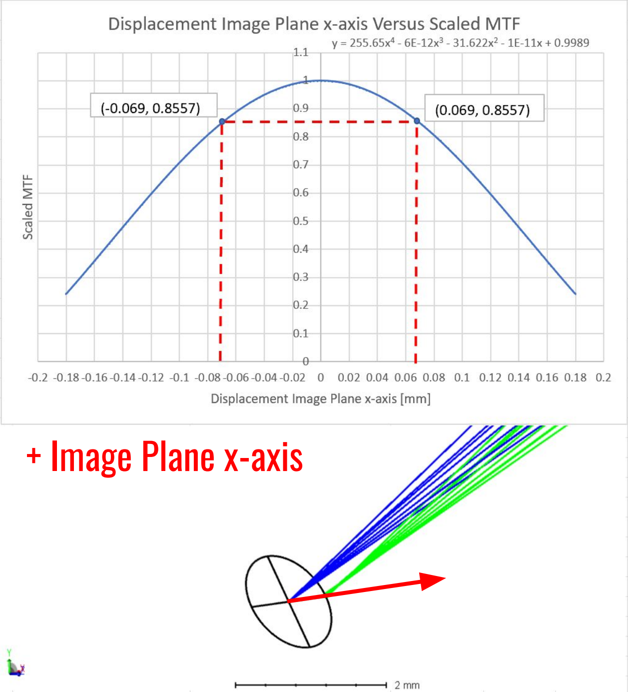
Displacement Range: ±520 μm

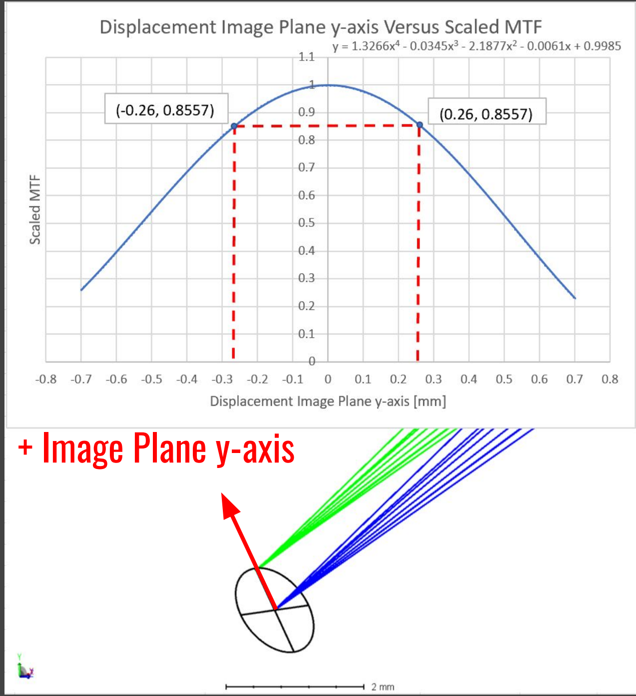
Ranges allow adjustments to mitigate MTF degradation

Shim Stock Options Available

Pinhole Alignment and Allowable Error

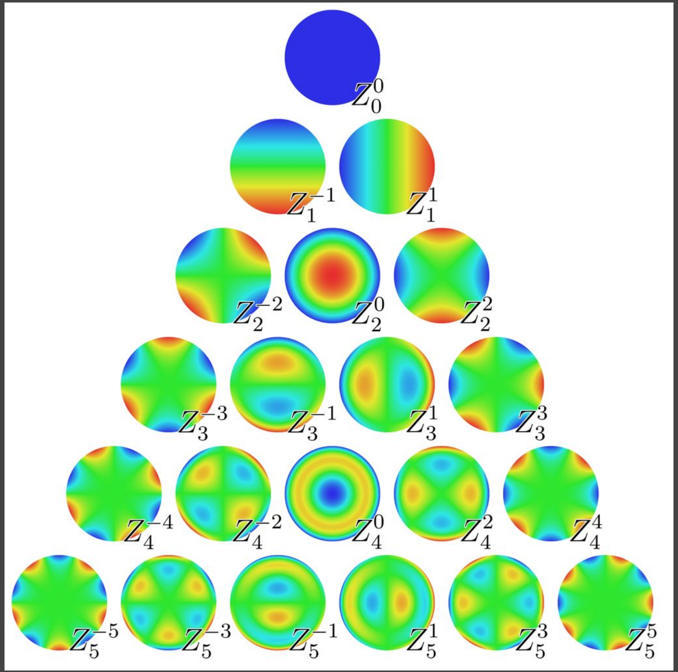






Zernike Coefficients

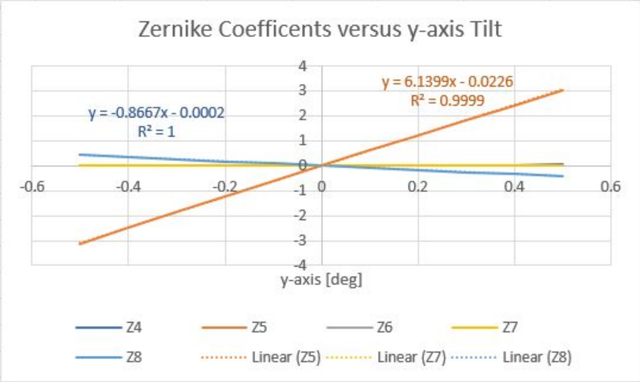
- Zernike polynomials are mutually orthogonal on the unit disk.
- Each Zernike polynomials corresponds to an optical aberration/irregularity
    - The order of Zernike coefficients is not universal
- Driving each Zernike coefficient toward zero decreases the measured wavefront error
    - The lower order Zernike modes have a ‘linearized’ relationship with respect to angular displacement
    - The decrease in wavefront error is visible in the fringe pattern output by the interferometer software
    - A null fringe pattern (as few waves as possible) corresponds to the best optical performance

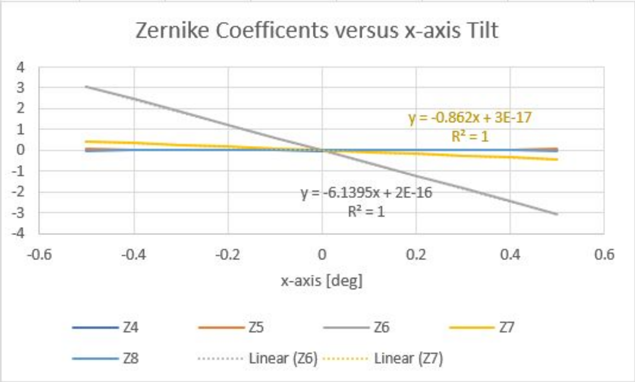


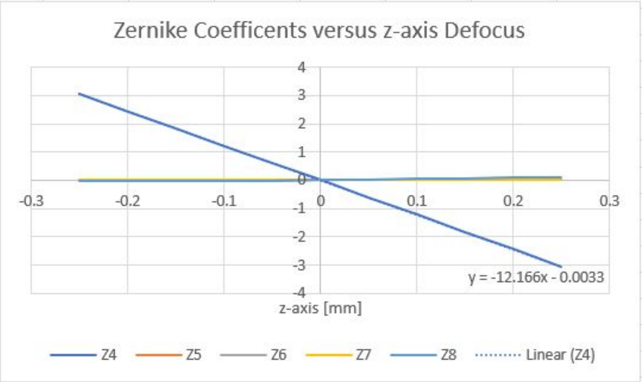
The Zernike modes - decreasing in order from top to bottom

Zemax Zernike Coefficients Model Verification

- Zernike coefficients measured from interferometer compared to Zernike coefficients modeled by Zemax

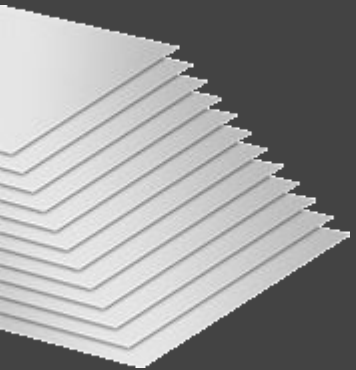






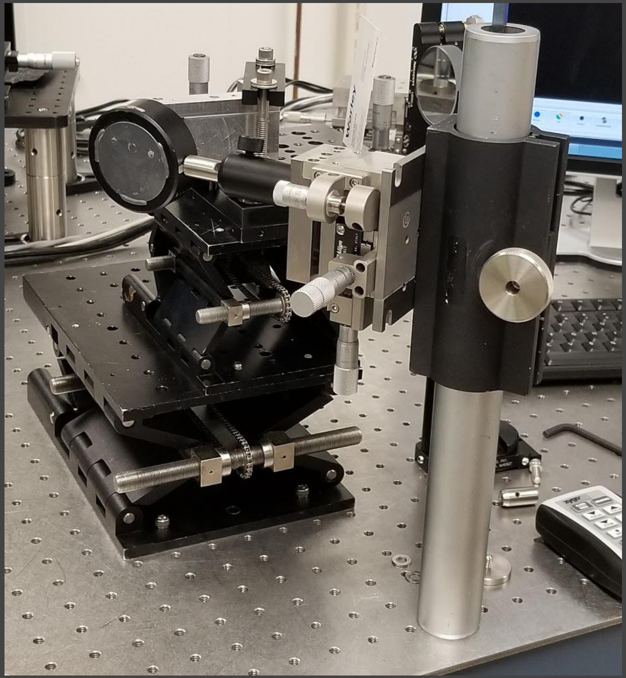
Pinhole Alignment and Allowable Error

- Summary of MTF Budget Analysis
  - Defocus Displacement Range = 138 μm (0.00543”)
  - Image Plane x-axis Displacement Range = 138 μm (0.00543”)
  - Image Plane y-axis Displacement Range = 520 μm (0.0205”)
- Shim Stock Thickness Recommendations
  - 1x 12.7μm (0.0005”) shim stock McMASTER-CARR 9502K56
  - 1x 25.4μm - 254μm (0.001” - 0.01”) shim stock set McMASTER-CARR 9300K5



Alignment Setup Stability

- Optomechanical mounting system
  - Stability of Test Environment
    - Interferometer laser stabilization after ~30 min of instrument being turned on
    - Isolator table not set up, but visual inspection of effects of vibration on fringe pattern is minimal.



Alignment to the Sun

- The system will need to be aligned to the Sun during the final day in the life test
  - From the Earth's surface, the apparent size of the Sun is around 0.5 degrees
  - Our optic system must be aimed somewhere on the solar disk near the center
  - So, the pointing accuracy must be less than 0.5 degrees (~0.1 degrees is reasonable)
- 2 tabs are aligned to the optimal axis of the OAP during the alignment procedure
  - The bright spot projected through a hole in the first tab is aimed at a crosshair which denotes the center of a hole in the second tab
  - The shadow cast by this crosshair is centered on the bright spot to align the enclosed system
  - This requires a window on the Sun facing side of the enclosure as well as one on the opposite side
  - The tabs being approx. 77mm apart means that 0.1 degree rotations result in the projected bright spot translating slightly more than ⅛ mm.
  - The shadow of the crosshair will disappear at a distance around 100x the width of the 'hairs'
  - A ⅛ mm thick crosshair will disappear around 1.25 cm passed the second tab

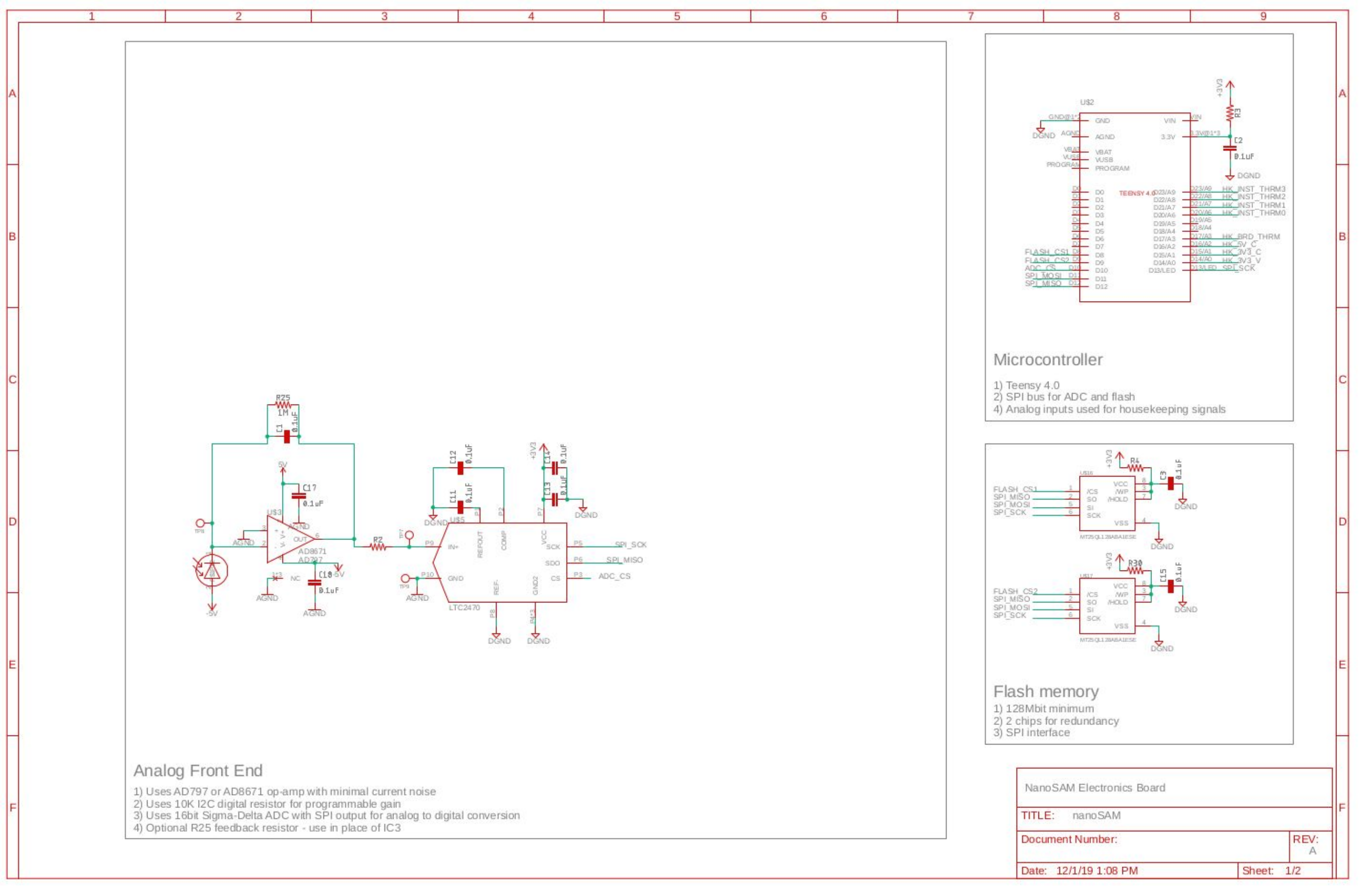
Electronics/Software

Electronic Design Keys

- Built-in contingency plans
  - Power supplies can be replaced
    - Analog power supply replaced with battery
    - Digital power supply replaced with microcontroller power
  - Op-amp footprint is standard to a large variety of op-amps
- Separate digital and analog power supplies
  - LT3260 bipolar analog power supply
    - Built in low noise linear regulators
  - LT8610 3.3V switching regulator digital power supply
- Separate digital and analog grounds
  - Continuous ground planes
- Payload power draw: 0.806 W

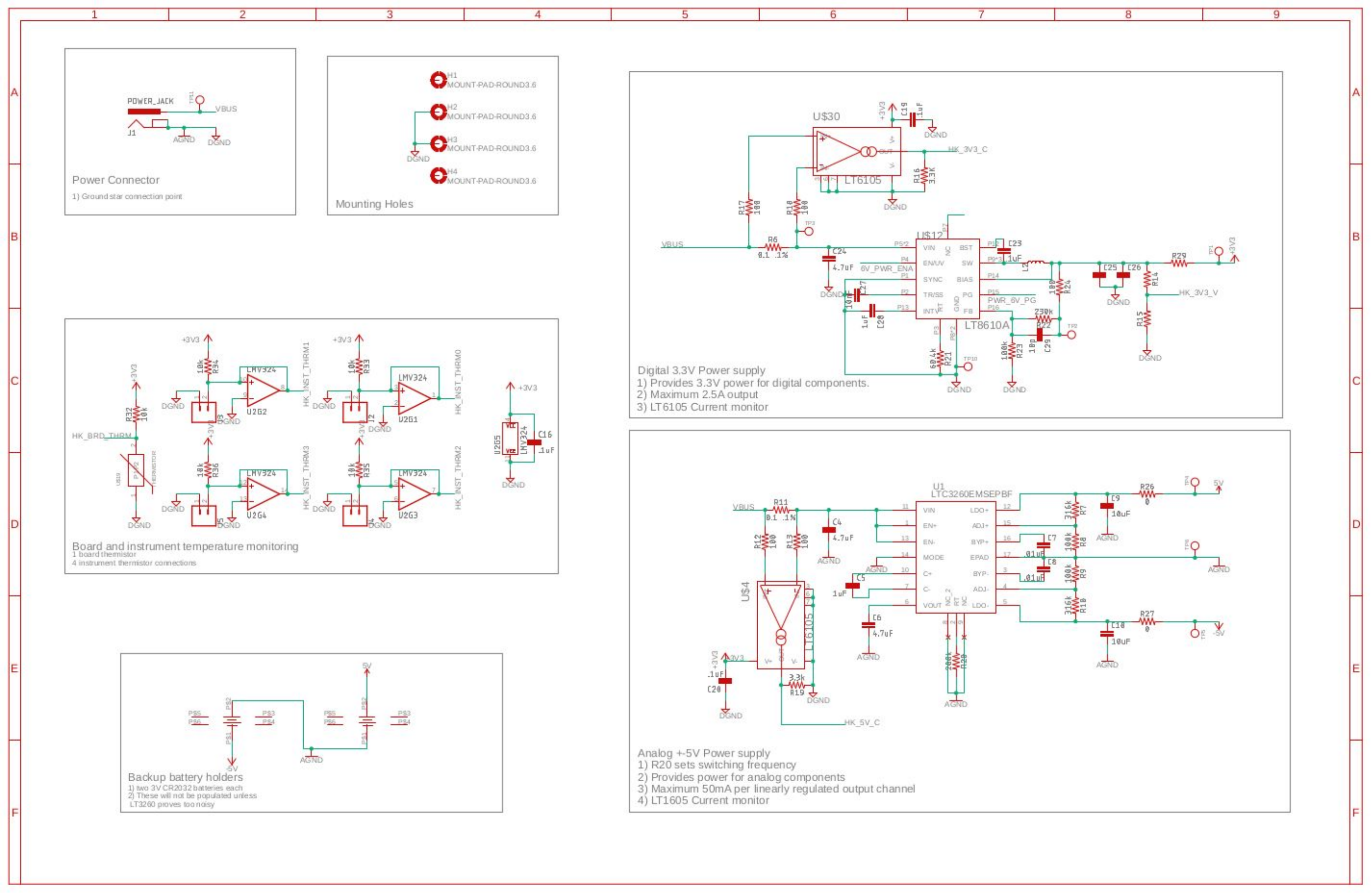
Satisfies Power Requirement!

Schematic



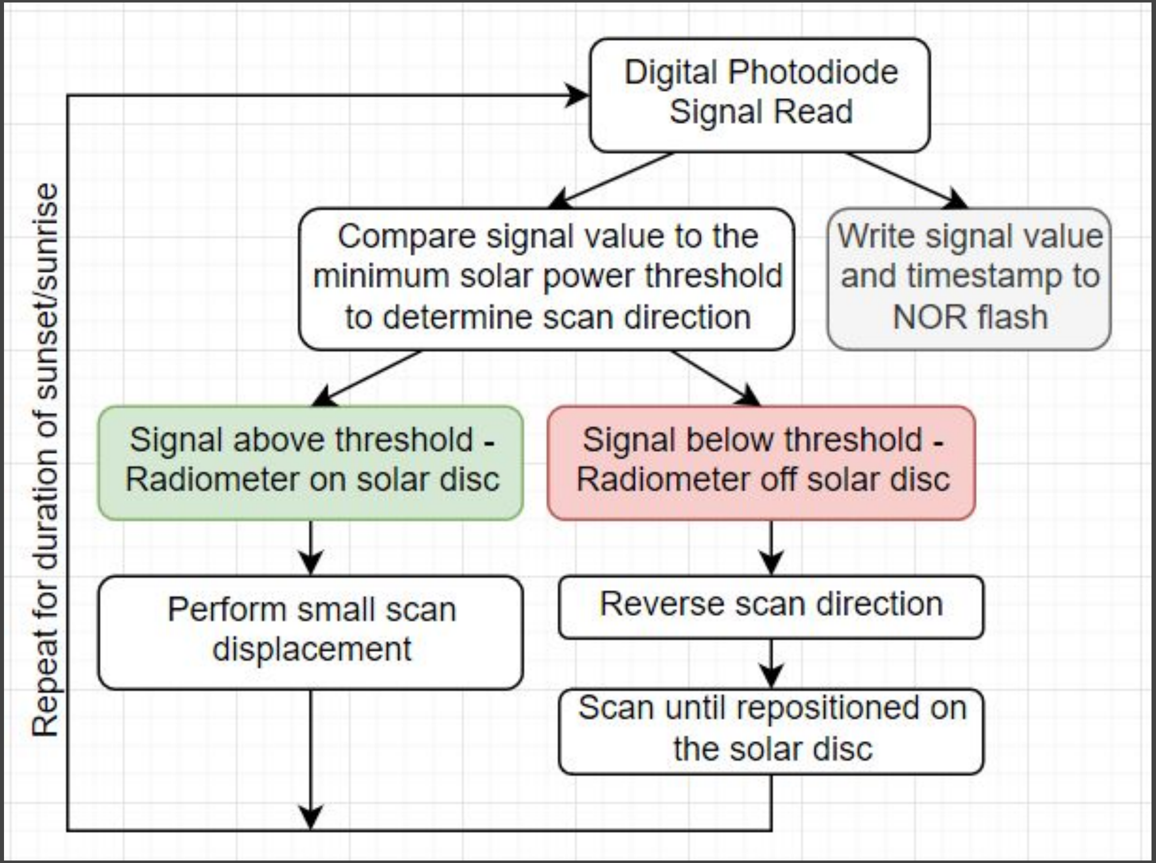
Microcontroller
1) Teensy 4.0
2) SPI bus for ADC and flash
4) Analog inputs used for housekeeping signals
Flash memory
1) 128Mbit minimum
2) 2 chips for redundancy
3) SPI interface
Analog Front End
1) Uses AD797 or AD8671 op-amp with minimal current noise
2) Uses 10K I2C digital resistor for programmable gain
3) Uses 16bit Sigma-Delta ADC with SPI output for analog to digital conversion
4) Optional R25 feedback resistor - use in place of IC3
NanoSAM Electronics Board
TITLE: nanoSAM
Document Number:
REV: A
Date: 12/1/19 1:08 PM
Sheet: 1/2

Schematic

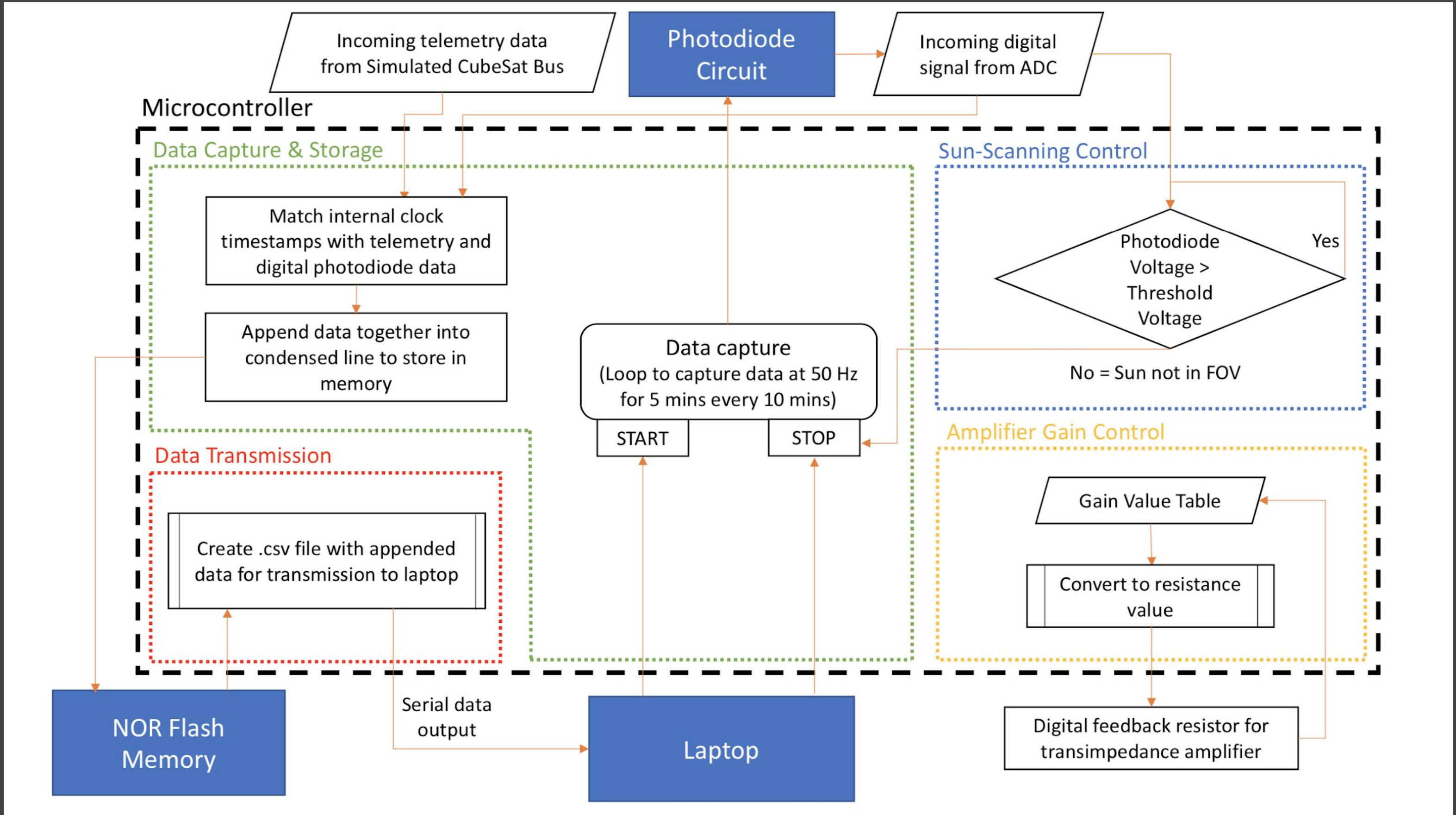


Power Connector
1) Ground star connection point
Mounting Holes
Digital 3.3V Power supply
1) Provides 3.3V power for digital components.
2) Maximum 2.5A output
3) LT6105 Current monitor
Board and instrument temperature monitoring
1 board thermistor
4 instrument thermistor connections
Backup battery holders
1) two 3V CR2032 batteries each
2) These will not be populated unless
LT3260 proves too noisy
Analog +-5V Power supply
1) R20 sets switching frequency
2) Provides power for analog components
3) Maximum 50mA per linearly regulated output channel
4) LT1605 Current monitor

Software Flowchart



Software Flowchart



Sample SPI Communications Code

```
SPI.begin();
pinMode(8, OUTPUT);     //pin 8 for Slave Select     //connected to pin 1 of flash mem 1
pinMode(9, OUTPUT);     //pin 9 for Slave Select     //connected to pin 1 of flash mem 2
pinMode(10, INPUT);    //pin 10 for Slave Select     //connected to pin 3 on ADC (ADC_CS)
```

```
pinMode(11, PIN_SPI_MOSI); //pin 11 for Master Output Slave Input (MOSI) - sends data to flash mem
pinMode(12, PIN_SPI_MISO); //pin 12 for Master Input Slave Output (MISO) - receives data from ADC
```

```
// SCIENCE DATA STORAGE (which pin inputs/outputs this data?)
    // take variable for digital data from ADC
    digitalWrite(10,LOW);
```

```
// write to NOR flash chips (??????)
SPI.beginTransaction(SPISettings(1000000,MSBFIRST,SPI_MODE3)); //SPISettings(maxSpeed,dataOrder,
digitalWrite(8,LOW); // set Slave Select pin 8 to low to select chip
SPI.transfer(data); //write data to chip
digitalWrite(8,HIGH); // set Slave Select pin 8 to high to de-select chip
SPI.endTransaction();
```

Systems/PM

Objectives	Level 3
Solar Irradiance	Linear The solar irradiance data exhibits approximately linear trends that will be independent of temperature variation .
Instrument SNR	The optical instrument has a SNR above 3.5E3. The level three goal shall be determined from the instrumental errors used in the Chu and McCormick sensitivity simulation with input from atmospheric scientists.
Vertical Resolution	The optical instrument's FOV facilitates a vertical resolution of 1 km of atmosphere when placed in a 500x500 km circular orbit.
Data Capture	Supporting electronics and software acquires, digitizes, packetizes, and downloads raw data from the photodiode to a laptop computer. The software also incorporates synthetic data that simulates the spacecraft health, slew rate, and other housekeeping (if applicable) digital outputs to represent actual operating conditions.
Payload Instrumentation Size	The payload consisting of a radiometer and supporting electronics is compatible with a 1U CubeSat bus.
Mechanical Structure	The payload will be secured into a mock 1U CubeSat bus architecture. The instrument and supporting electronics will be secured into place along with "black boxes" that represent items that will be present in the final mission but that are not present in this year's project such as the ADCS.

Design Requirements

RQMT ID	RQMT Title	RQMT Text	Verification Approach	Verification Method
1.2	MTF	The MTF of the optical system shall be at least 0.74.	THe MTF of the optical system will be obtained from an interferometer.	T
1.1	SNR	The payload shall have an SNR of 3500 or greater for irradiance values of 50% maximum anticipated irradiance and above.	An analytical model of the SNR will be produced with worst case scenarios in mind to ensure the minimum SNR remains above the specified value.	A
1.3	Measurement Stability	The irradiance measurements of the system shall remain stable to within 1% across at least 5 number of tests.	A calculation of the expected signal will be used to verify the gains setting that allows the irradiance measurements to be stable.	A/T
1.4	Dynamic Range	The Payload shall not saturate for a radiance input of 120% of the maximum anticipated solar radiance in the operational band.	A light source with 120% of the anticipated solar radiance will be measured to verify the instrument does not become saturated.	T
1.5	Allowable Measurement Error	The irradiance measurements of the system shall remain accurate to within 5% of theoretical signal.	A calculation of the theoretical signal will be compared with the experimental results to ensure accuracy of measurements.	T
1.6	Optical Heating	The optical system focal length shall remain stable over the anticipated operating temperature range of 4C to 26C.	The optical system focal length will be compared to an expected value in temperature range.	A/T

Design Requirements

RQMT ID	RQMT Title	RQMT Text	Verification Approach	Verification Method
1.7	FOV	The optical system FOV shall be less than 1.2 arcminutes.	The FOV will be calculated analytically and checked to ensure conformity.	A
1.8	Pointing Accuracy	The pointing accuracy of the payload shall be 30 arcseconds or less. (Solar tracker for test)	The pointing accuracy of the payload will be analytically determined from the solar tracker properties.	A
1.9	Band pass Filter	The optical system shall utilize a band pass filter with a theoretical center wavelength of 1.02 micron with a bandwidth of 40 nm. The filter used must have an actual bandwidth of at least 25 nm and include the 1.02 micron wavelength.	A light source with no wavelengths in the specified range will be applied through the filter and tested to ensure no light has passed through.	T
1.10	Average Power Draw	The payload shall draw an average of less than 4.5 W over one orbit.	The maximum power required by all electronic components that require power will be calculated and measured.	A/T
1.11	Sampling Rate	The irradiance data shall be sampled at a rate of at least 50 Hz.	The payload will be tested to show that it collects data at a rate of 50 Hz or more.	T
1.12	Data Collection Bit Size	The irradiance data shall be collected using 10 or more bits.	The payload will be tested to show that it collects data at 10 or more bits.	T
1.13	Data Storage	The payload shall be able to collect and store at least 100 Mb of data for 24 hours.	120 Mb of experimental data will be collected and stored during overall system testing.	T

Design Requirements

RQMT ID	RQMT Title	RQMT Text	Verification Approach	Verification Method
2.1	Payload Mass	The payload and bus architecture combined shall have a mass of 1.33 kg or less.	The mass of all components will be weighed before and after assembly to ensure the total mass is less than 1.33 kg.	I
2.2	Payload Volume	The optics and electronics system shall fit within a volume of 10x10x10 cm.	The optics and electronics systems will be placed into the housing with the specified dimensions.	I
2.3	Housing	The system shall be housed in an enclosure with external dimensions of 10x10x15 cm.	The optics and electronics systems will be placed into the housing with the specified dimensions.	I
3.1	Data Transmission	The system shall be able to transmit all recorded data to an external source.	Data will be taken and transmitted to an external source.	T
3.2	Communication Timing	The system shall be able to receive timing and duration information from an external source.	Data will be taken and transmitted to an external source.	T

Test Plan

Test Phase	Location	Support Equipment	Requirements Verified
Optical System Alignment (2/20-3/7)	JILA	Interferometer, Optical shims, Precision half-sphere, torque wrench	MTF, FOV (Vertical Resolution)
Stability Testing (3/8-3/21)	Ball	Gradient filter and associated equipment, highly regulated power source, tungsten bulb, oscilloscope	SNR, Stability, Error, Dynamic Range, Band pass filter, Sampling rate, Data bits, Data transmission
Integration Testing (3/22-4/10)	CU Business Field	Solar tracker, tripod, GPS, solar tracker to NanoSAM mount	Optical heating, Pointing accuracy, Power draw, Data storage, Payload mass and volume, Housing, Timing communication

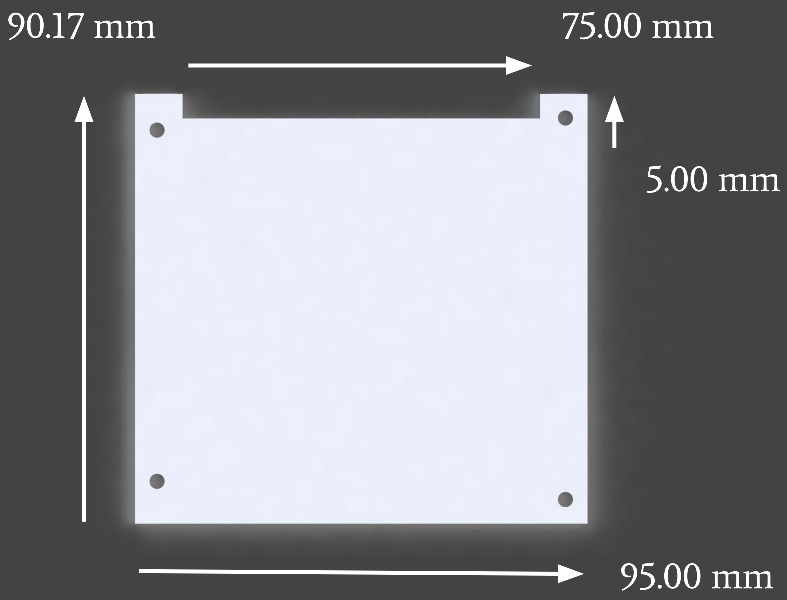
Test Plan

RQMT Verifying	Test Description	Support Equipment
1.1	An analytical model of the SNR will be produced with worst case scenarios in mind. Physical measurements of noise of the electronics will be made to incorporate into the model. The value derived from this model will be compared with the required value to ensure the SNR is met.	Electronics system, photodiode, oscilloscope
1.2	During alignment of the system using the interferometer the MTF of the system will be output by the interferometer.	Interferometer, precision half sphere, half sphere removal tools
1.3	A regulated light source will be increased from 0% radiation to 120% maximum expected solar radiation and irradiance measurements will be taken to ensure the photodiode does not become saturated.	Regulated light source, optics system
1.4	A regulated light source will be measured for irradiance with the optics system and compared to the theoretical value over the anticipated operating temperature.	Regulated light source, optics system
1.5	Using an interferometer with a regulated light source held at a constant irradiance value the focal length of the optical system will be determined and evaluated for conformance over the anticipated operating temperature.	Regulated light source, optics system, interferometer
1.6	The FOV will be determined analytically using measurements of the system's actual aperture diameter.	Optical system, ruler

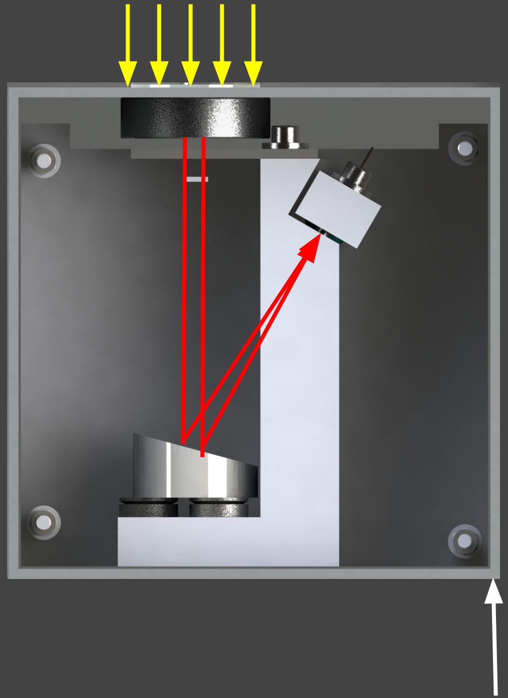
Test Plan

RQMT Verifying	Test Description	Support Equipment
1.7	The pointing accuracy of the solar tracker will be analytically determined using data from the solar tracker specifications.	Solar tracker
1.9	A power budget for the system will be analytically formulated and the electronics system will be tested to ensure the power draw conforms to the required value.	Electronics system, electronics measurement equipment
1.10	Data will be captured by the system for a set amount of time and analyzed to ensure sampling of at least 50 Hz.	Electronics system, oscilloscope
1.11	Data will be captured by the system and specific packets of information will be examined to ensure 10 bit data transmission.	Electronics system, oscilloscope
1.12	During various tests data will be taken, including 120 Mb of experimental data during overall demonstration.	Payload, external computer source
2.1	The overall system will be weighed using a scale.	Payload, scale
2.2	The optics and electronics system will be placed into the external housing and inspected to ensure a proper fit.	Payload, external housing
2.3	The optics and electronics system will be placed into the external housing and inspected to ensure a proper fit.	Payload, external housing
3.1	During various tests data will be taken and captured, the presence of all recorded data will be checked for.	Payload, external computer source
3.2	During various tests the payload will be commanded by the external computer source. The implementation of these commands and subsequent data capture will be monitored for.	Payload, external computer source

Stack Plate

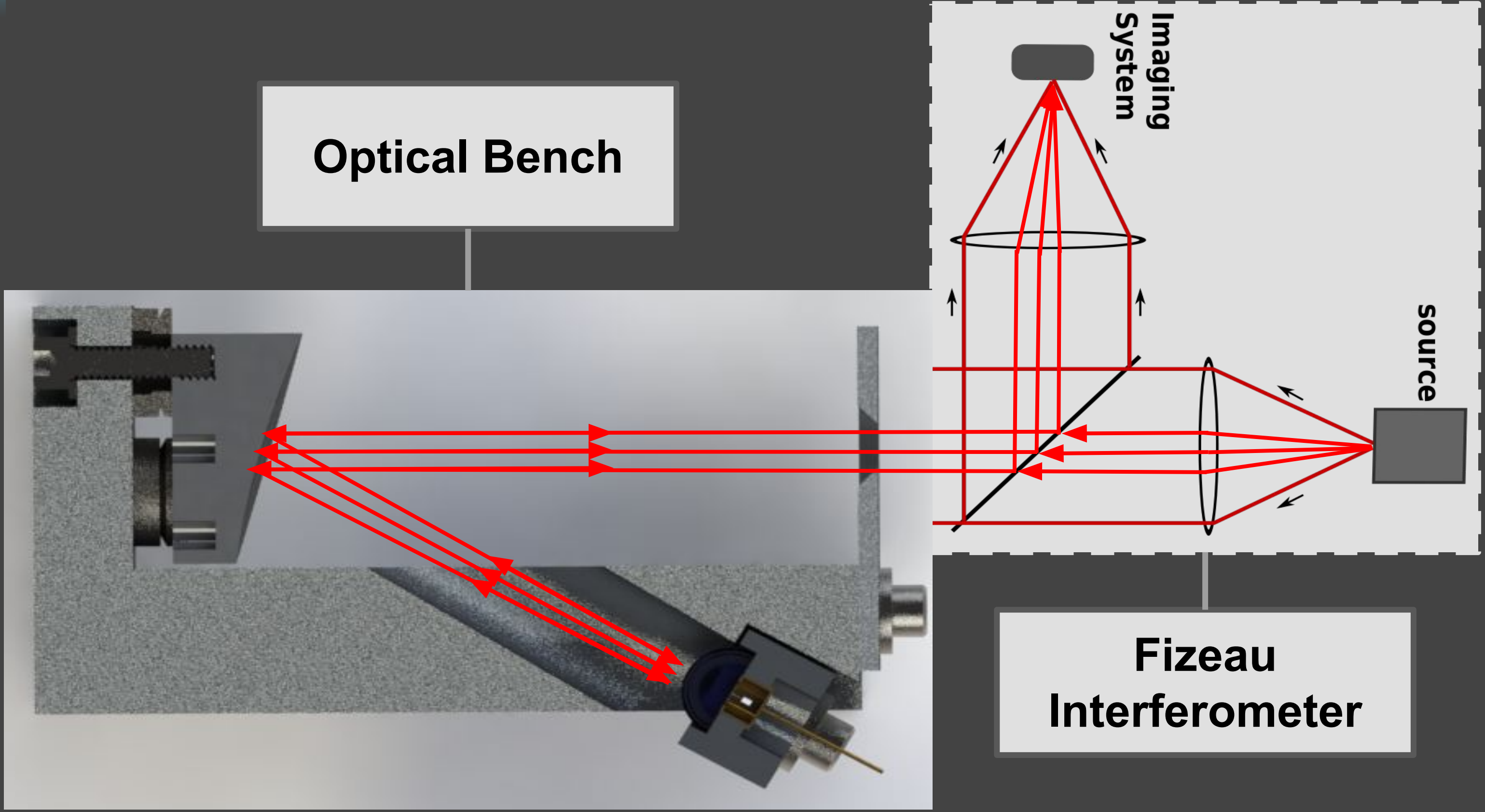


PC/104 thru hole specification



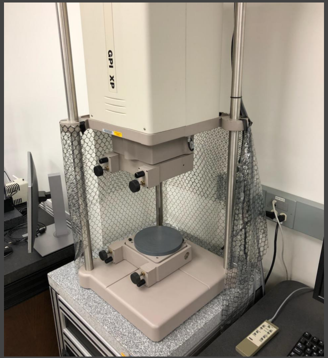
0.5 mm spacing b/w plate and enclosure

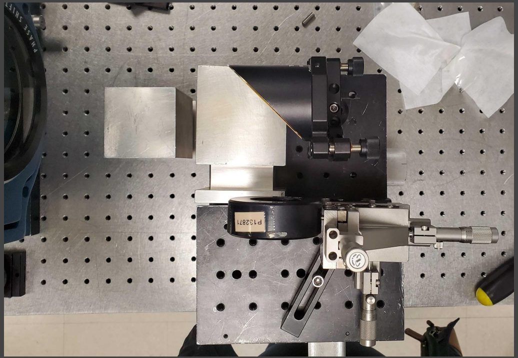
Alignment Verification

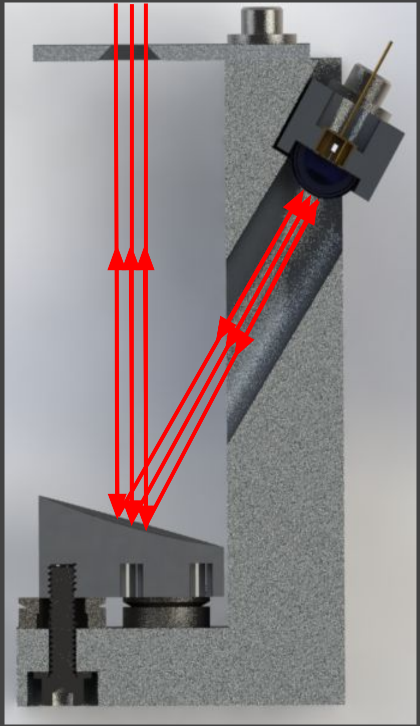


Optical Integration Preparation

- Confirmed Fizeau interferometer access at JILA
  - Facility will be used for practice alignment
- Confirmed Fizeau interferometer access at Ball Aerospace
  - Facility will be used for final alignment
  - Optomechanical mounting hardware on site
  - Precision reference sphere on site

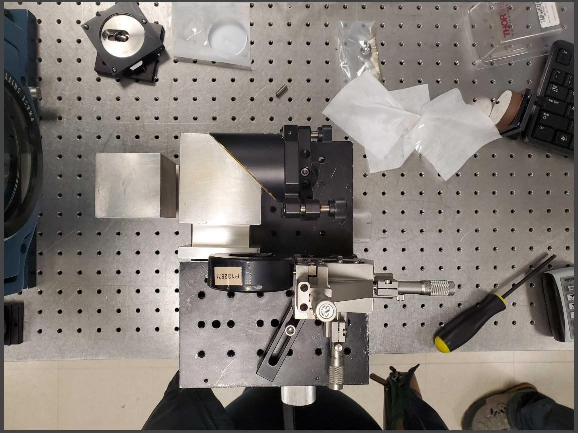






Alignment Integration

- Practice alignment sessions at JILA
  - Diode Tube and Reflective Half Sphere
- Final alignment at Ball Aerospace
  - DinaFiz Fizeau interferometer
  - Precision reference sphere
  - Optomechanical hardware on site
- Zemax aberration model preparation



Final integration of optical bench components during alignment phase