Ocean Color Experiment Ver. 3 (OCE3)

~ Final Package~

IDL Systems Engineering

June 19, 2012

The IDL Team shall not distribute this material without permission from Betsy Edwards (Betsy.Edwards@nasa.gov)

Total Instrument Rack-up

(no contingency included)

OCE3 Ocean Color Experiment (Version 3)	Total Mass	Total Operating Power (Effective Average)	Total Data Rate
OCE3 **Scan Drum Assembly** Scanning Telescope Assembly Drum Housing Scan Drum Motor / Inductosyn Half Angle Mirror Assembly Half Angle Mirror Motor / Inductosyn Calibration Target Assembly Calibration Target Stepper Motor / Resolver **Momentum Compensation Assembly** Momentum Compensation Motor/Resolver Momentum Compensation Wheel Momentum Compensation Wheel Housing **Cradle Assembly** Cradle Structure Tilt Mechanism Bracket Tilt Mechanism Motor 1/ Resolver Tilt Mechanism Motor 2/Resolver **Aft Optics/Detector Assembly** 1 Km Lens/Detector "six Pack" Assembly 1 Km Fiber Detector Assembly 250 M Fibers Detector Array Assembly 250 M Visible Channel 1 Km Blue-Red Channel CCD Structure **Mechanism Control Electronics Box** **Main Electronics Box** **Digitizer Electronics Box** **Purge and Venting** **Harness** **Thermal Subsystem**	*279.2 Kg* *Detailed on Page 22,23*	389 W (includes 47 W of operational heater power)	**Average Data Rate:** 125.5 Mbits/s (scan average) **Data Capacity Needs:** 377 Gbits/orbit 5400 Gbits/day

OCE3 Study Parameters

- **Delivery Date: 6/2018**
- **Orbit:**
  - Thermal Analysis assumes 11:00 AM descending crossing
  - Goal: Noon equatorial crossing time and altitude of ~700 km
- **Mission Class: C (with selective redundancy)**
- **Mission Duration: 3 to 5 years**

Operational Concept

- **Continuous scanning**
  - Raster scan with +/- 51 deg cross track science view
  - Global coverage in two days
  - IFOV 1 km^2 +/- 10%
- **Sunlit portion of orbit, +/- 90 deg lat.,**
- **Solar calibration viewing when available during orbit (at terminator crossings) 1x per day**
- **2x orbit inst. tilt pointing (ala SeaWiFS) to +/- 20 deg. for sun glint avoidance (minimization)**
- **monthly S/C slews for Lunar calibration scans**

Science Objectives

OCE 3 will provide data for both the ocean color and atmospheric science communities. The choice of channel wavelength, band-pass, spatial resolution, and signal-to-noise for OCE 3 is intended to satisfy the PACE Mission (PACE : Pre-Aerosol, Clouds, and Ocean Ecosystem).

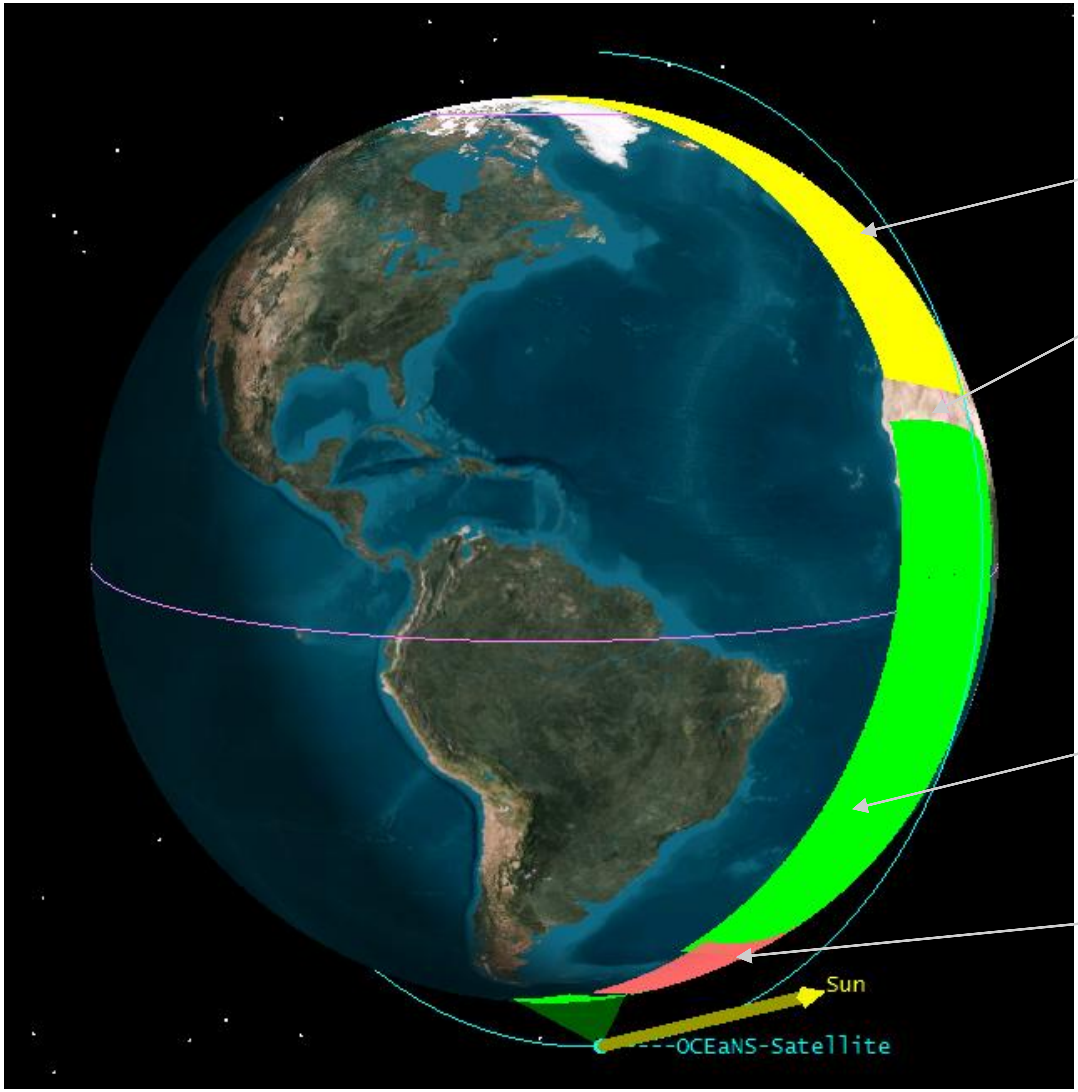
Visible channels span 350 nm to 830 nm. These are addressed in OCE3 with focal plane slits and spectrometer gratings and prism components to provide 5 nm channel spacing (results in 96 channels in the visible). Collected at both 250 m (prism) and 1 km (grating) resolution at increased signal-to-noise ratio enabled by a slower scan rate from that studied in OCE2 (1/3 the rate).

Near-infrared, short-wave infrared, and discrete visible channels are addressed by fiber optic collection at the focal plane and provide information at (mostly) larger band-passes at 250 m and 1 km resolution.

See Radiometry Package by Jay Smith for Further Information

Forward and Aft Scans Switched at Sun Zenith

Instrument Synthesis & Analysis Laboratory



Aft Scan

Switch at Sun Zenith

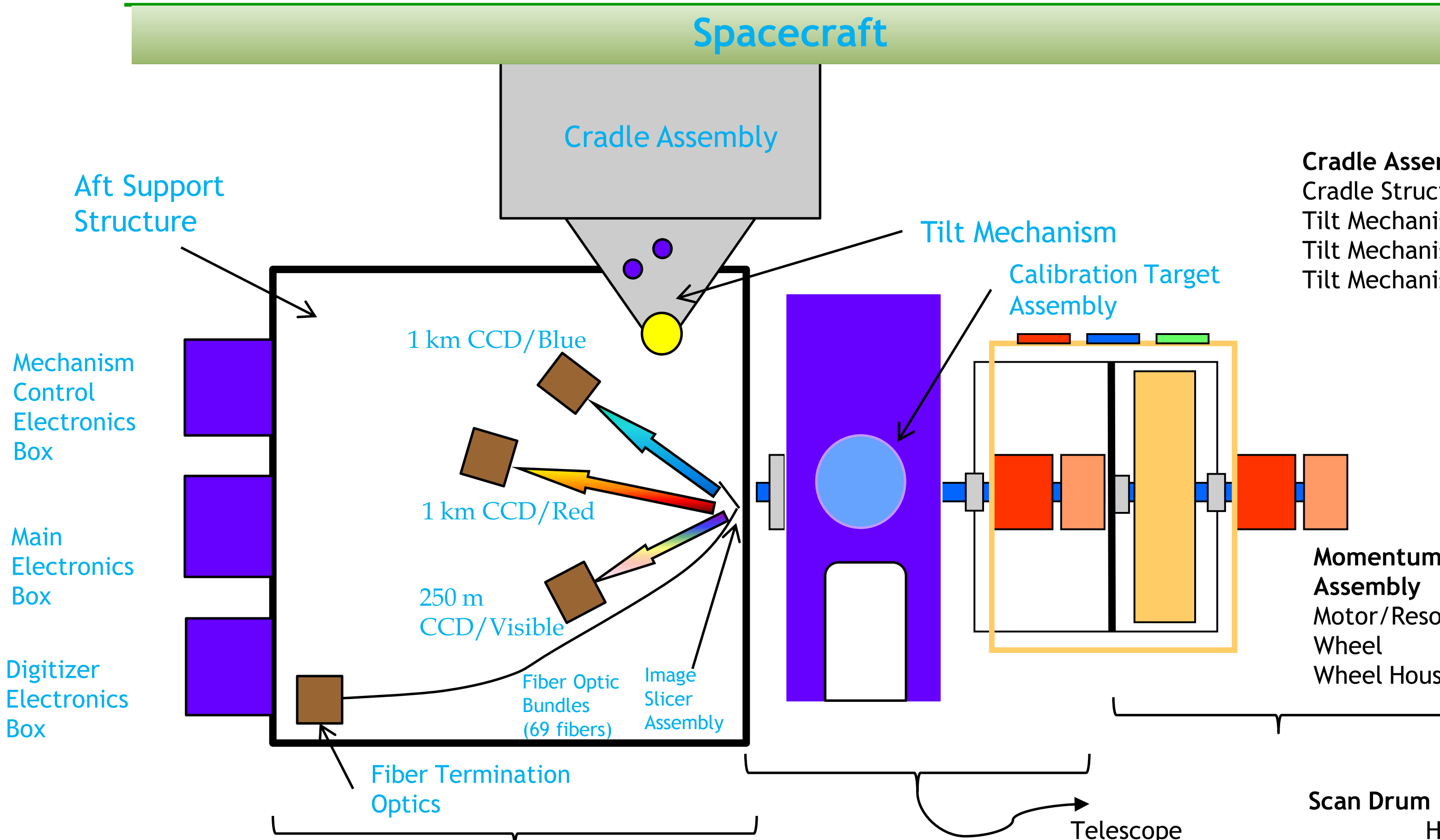
Forward Scan

Cal. Scan

Optical Telescope Parameters

Effective Focal length (mm)	600
F/#	3.3
FOV	0.8 x 0.8
Wavelength range (nm)	350 - 2400
Pupil Diameter (mm)	180

OCE3 Top Level Block Diagram



Cradle Assembly
Cradle Structure
Tilt Mechanism Bracket
Tilt Mechanism Motor #1/Resolver
Tilt Mechanism Motor #2/Resolver

Momentum Compensation Assembly
Motor/Resolver
Wheel
Wheel Housing

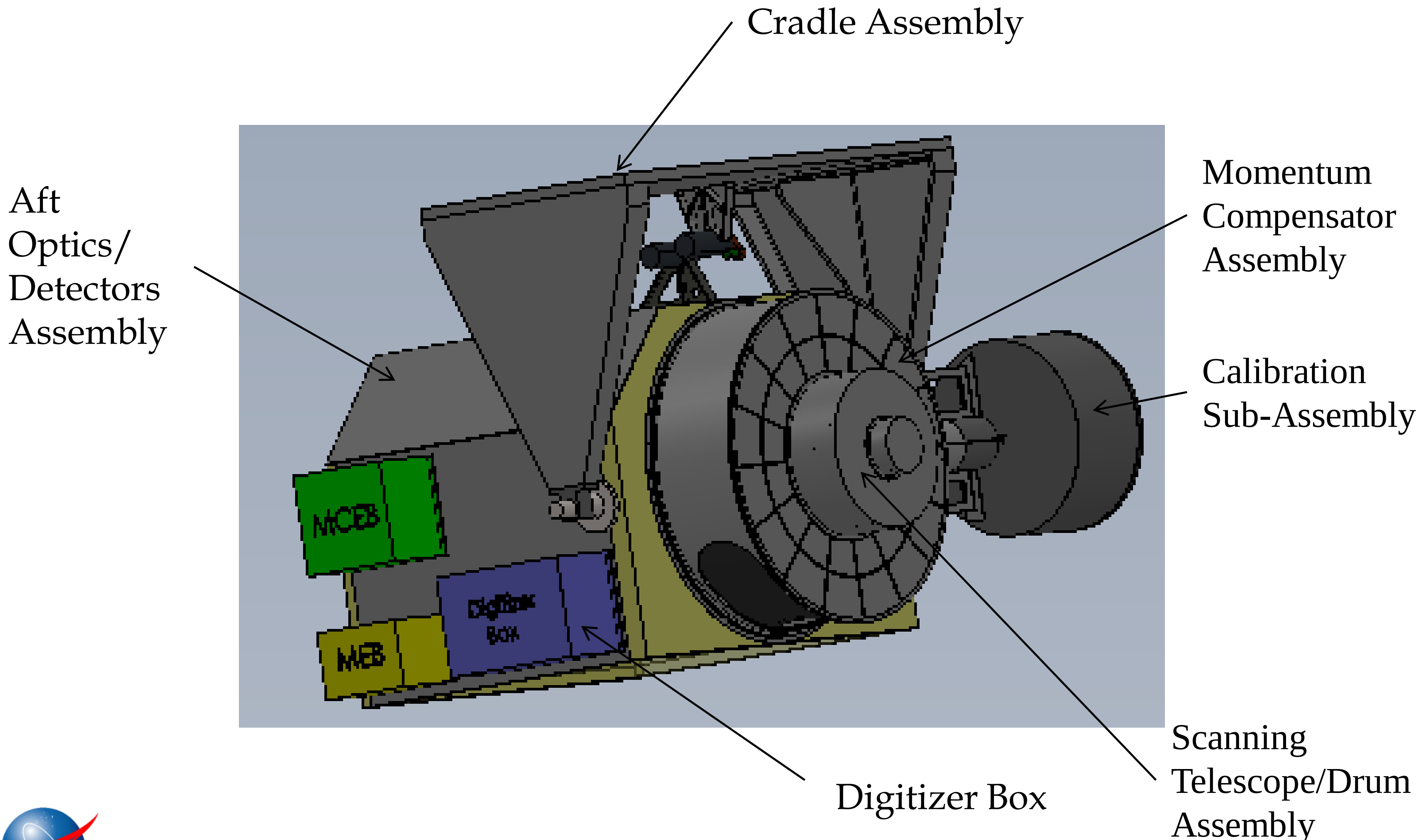
Aft Optics / Detector Assembly

Aft Support Structure	1 km Red CCD	Digitizer Electronics Box
Image Slicer Assembly	1 km Blue CCD	Mechanism Control Electronics Box
Red Optics & Support Struc.	250 m VIS CCD	Main Electronics Box
Blue Optics & Support Struc.	Silicon PIN PD	
250 m VIS Optics & Support Struc .	InGaAs PIN PD	
Fiber Termination Optics	Pre-Amp, FETs	

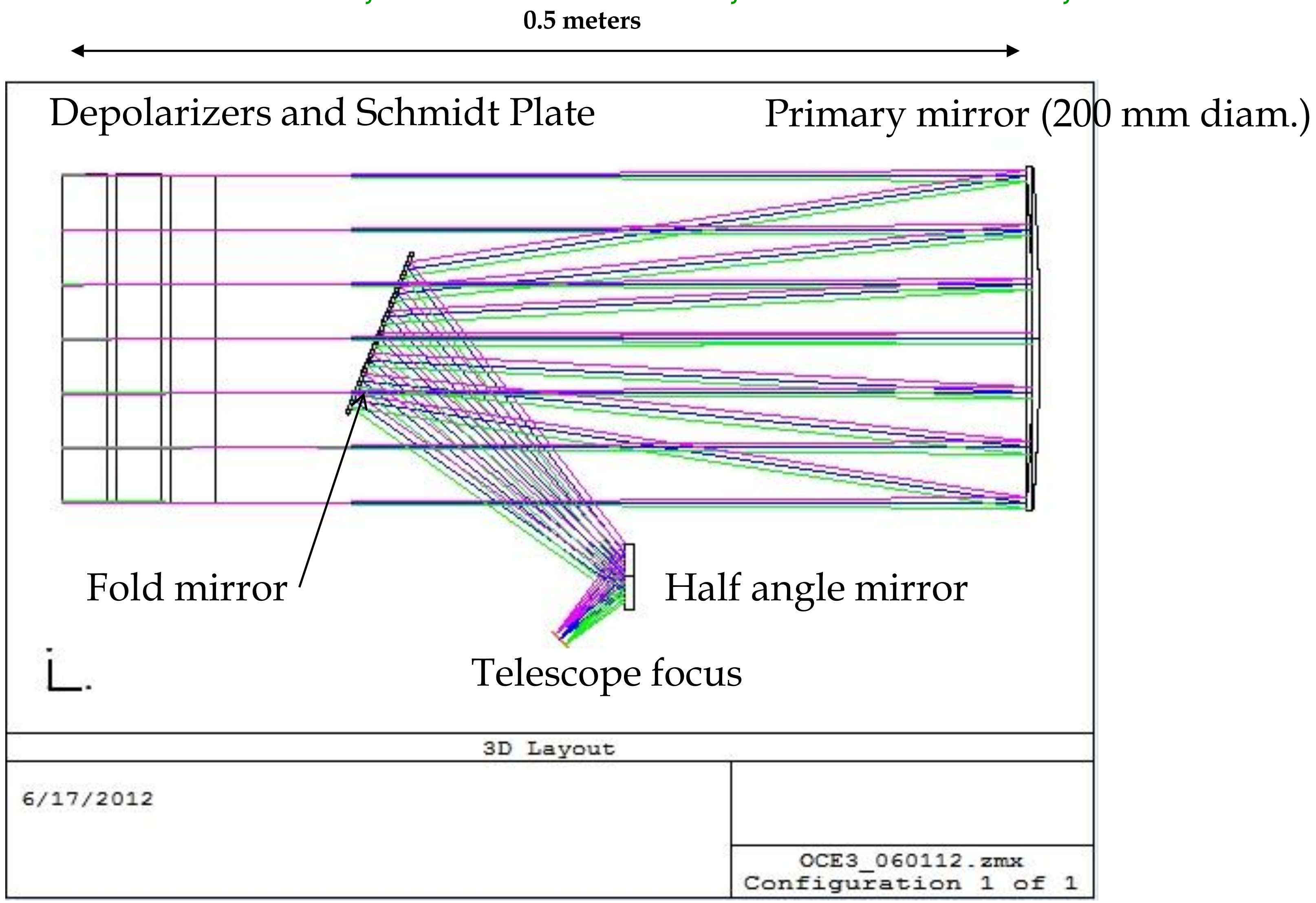
Scan Drum Assembly

Telescope	Half-Angle Mirror Assembly
Drum Housing	Half-Angle Mirror Motor
Scan Drum Motor	Half-Angle Inductosyn
Scan Drum Inductosyn	
Half-Angle Mirror Assembly	
Calibration Target Assembly	
Calibration Target Stepper Motor/Resolver	

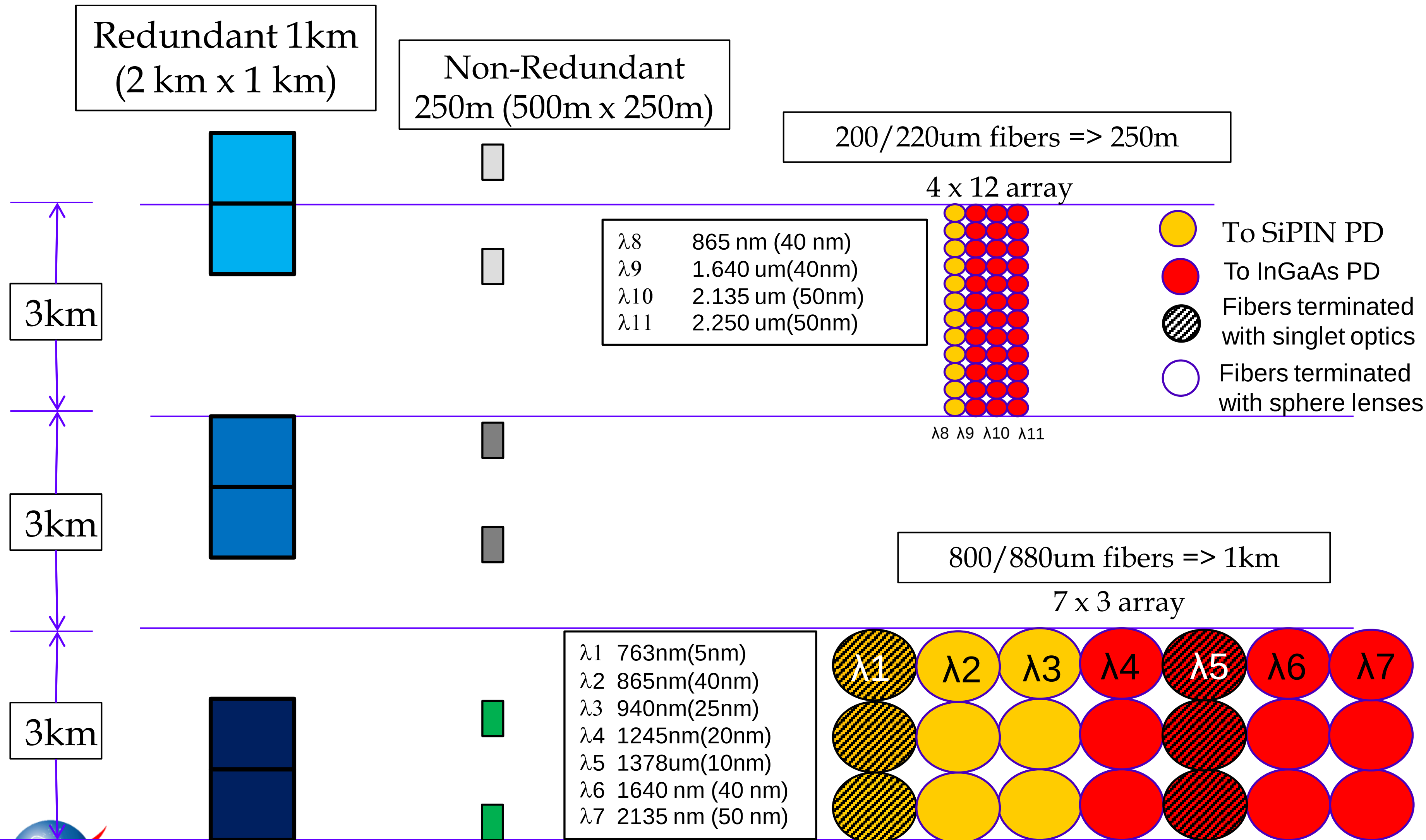
OCE3 Mechanical Concept



Telescope Layout



Final Baseline Focal Plane Slit/Fiber Layout



Fiber-Optics Termination Designs

- **Singlet Optics Termination (used on 6 of the fibers)**

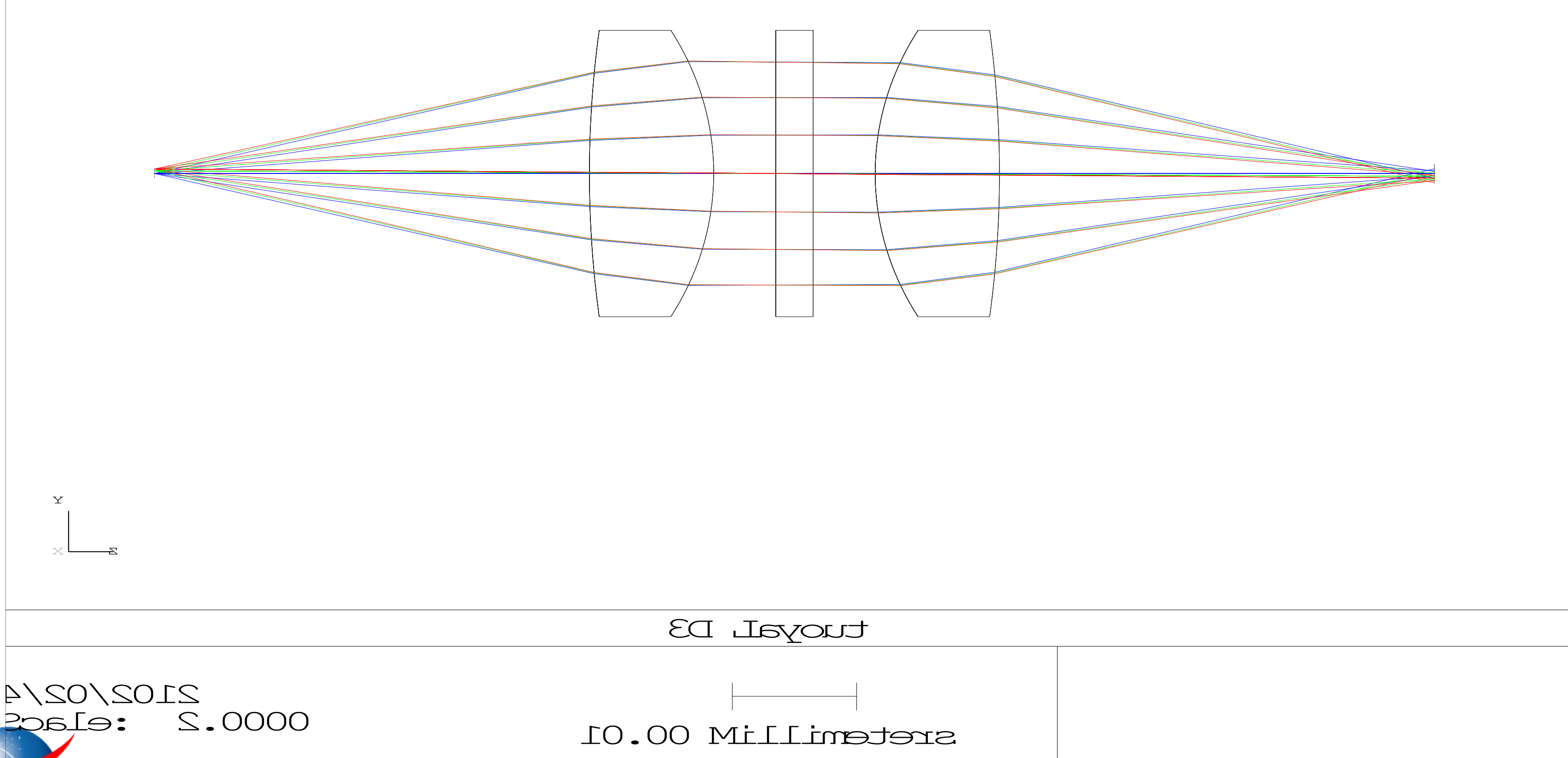
Identical to the concept employed on the fibers for OCE2 effort.

- **Ball Lens Termination (used on 63 of the fibers)**

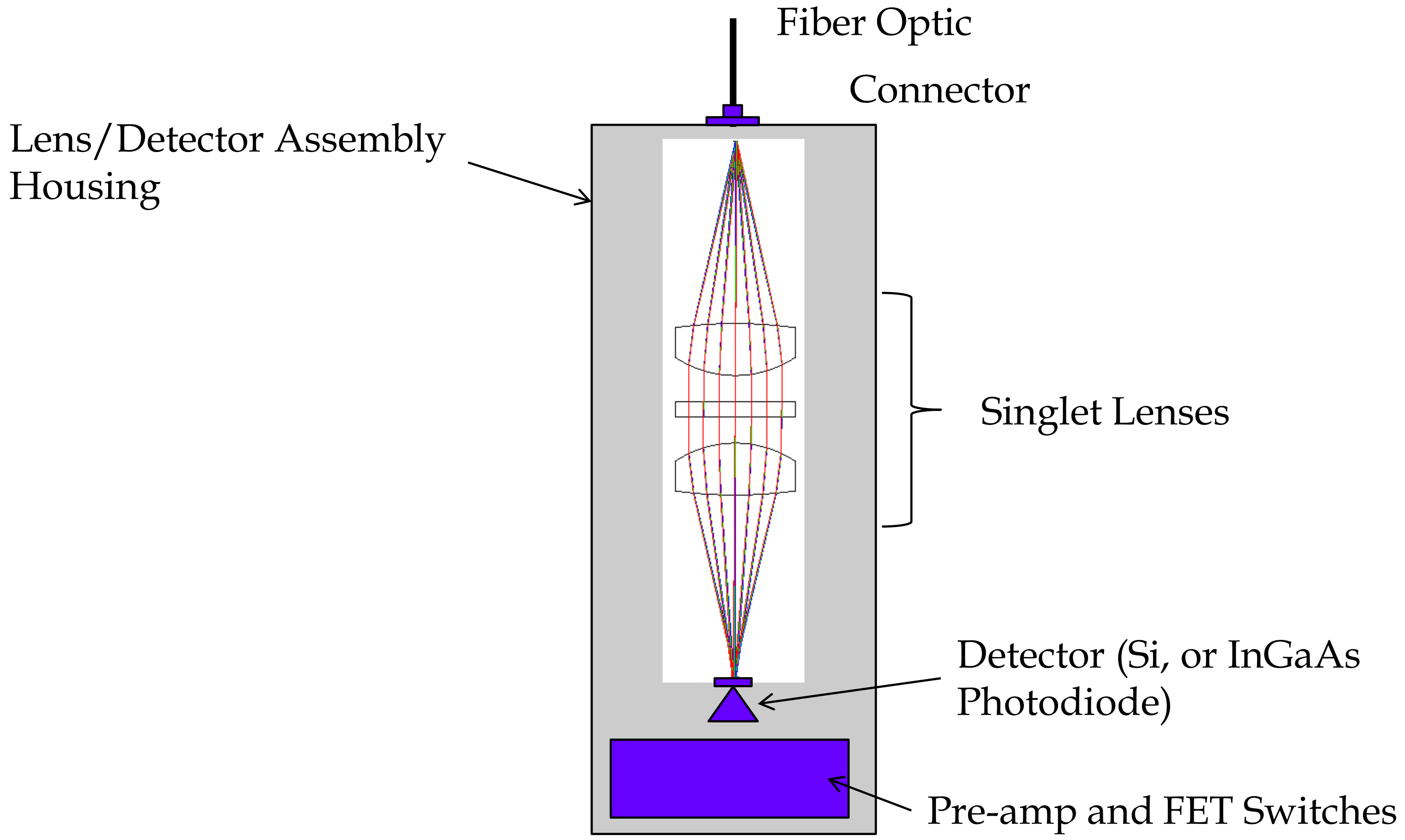
Lower Technology Readiness Level (assessed at 4 or 5). Used on wider bandwidth channels. A commercial method is available as is the singlet optics method (as used on all fibers for OCE2).

Fiber Receiver Optics (Singlet) Termination

- Six (6) singlet optics assemblies used on narrow band-bass channels fed by 800 μm / 880 μm fibers.
- Baselined for 763 nm (5 nm), 1378 nm (10 nm) at 1 km resolution

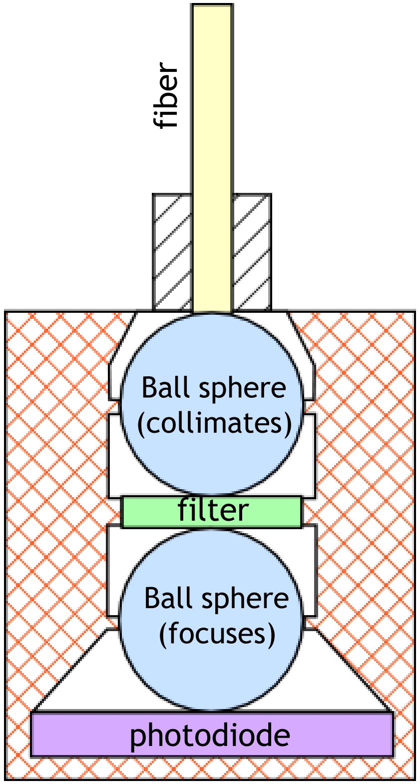


Lens/Detector Assembly



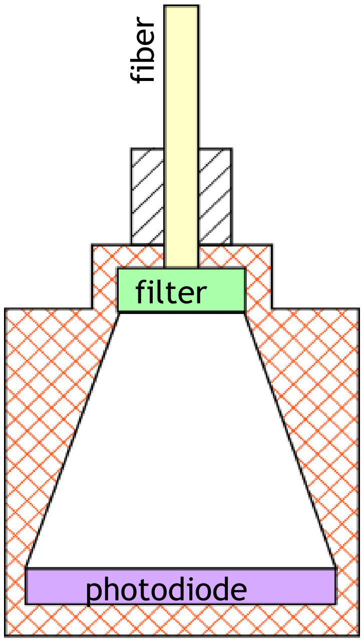
Additional Fiber Termination Options

Baseline: Used for 63 of 69 channels and is incorporated in the master equipment list)



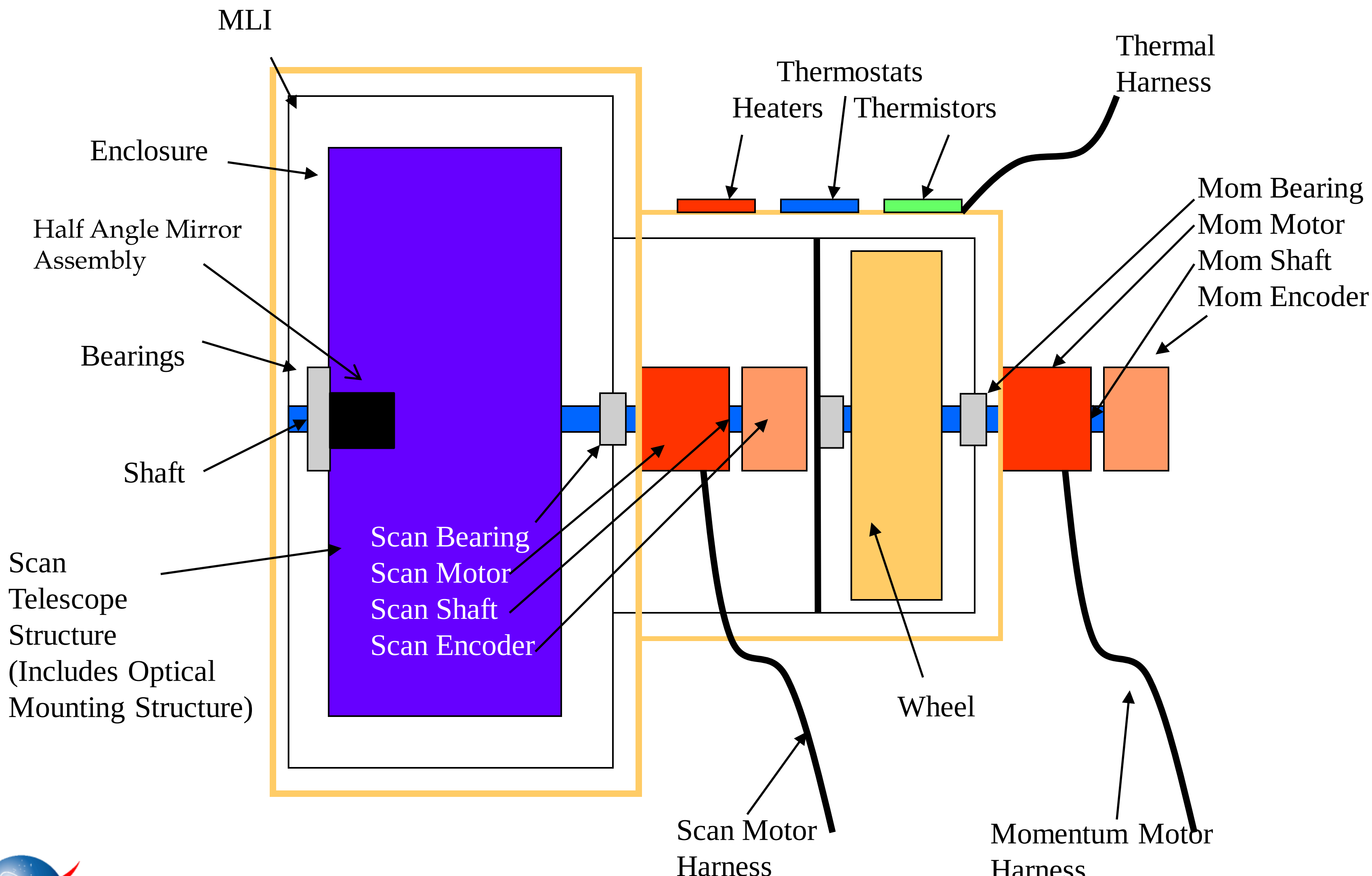
Other (commercial) method of filter termination available.

As described by industry (2 vendors)

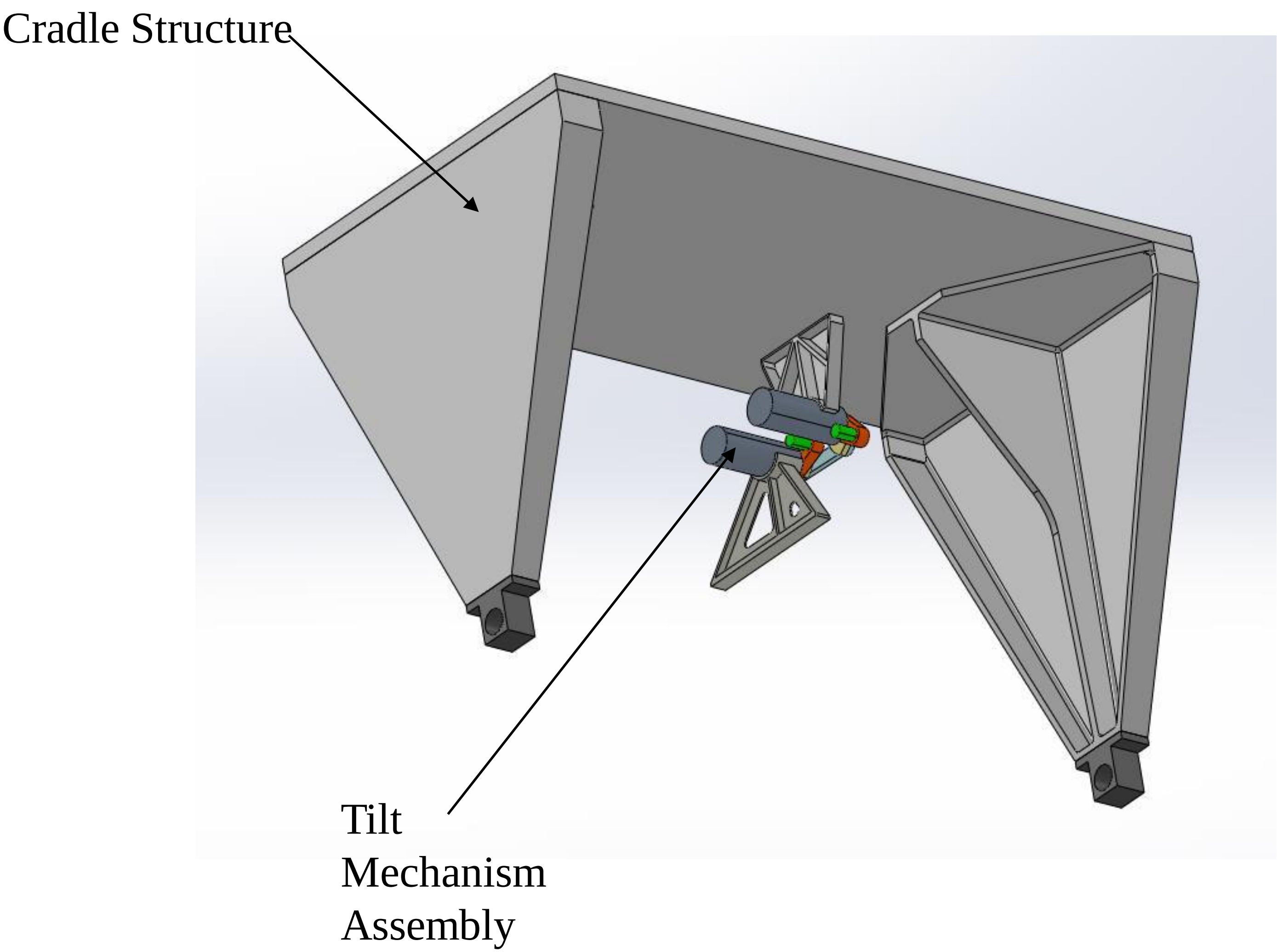


We suspect this is the function inside the connector terminator, as the vendor did not disclose it - it is not ideal because incident light on the filter is coming in at off normal angles

Scan Telescope and Momentum Compensation Notional Block Diagram

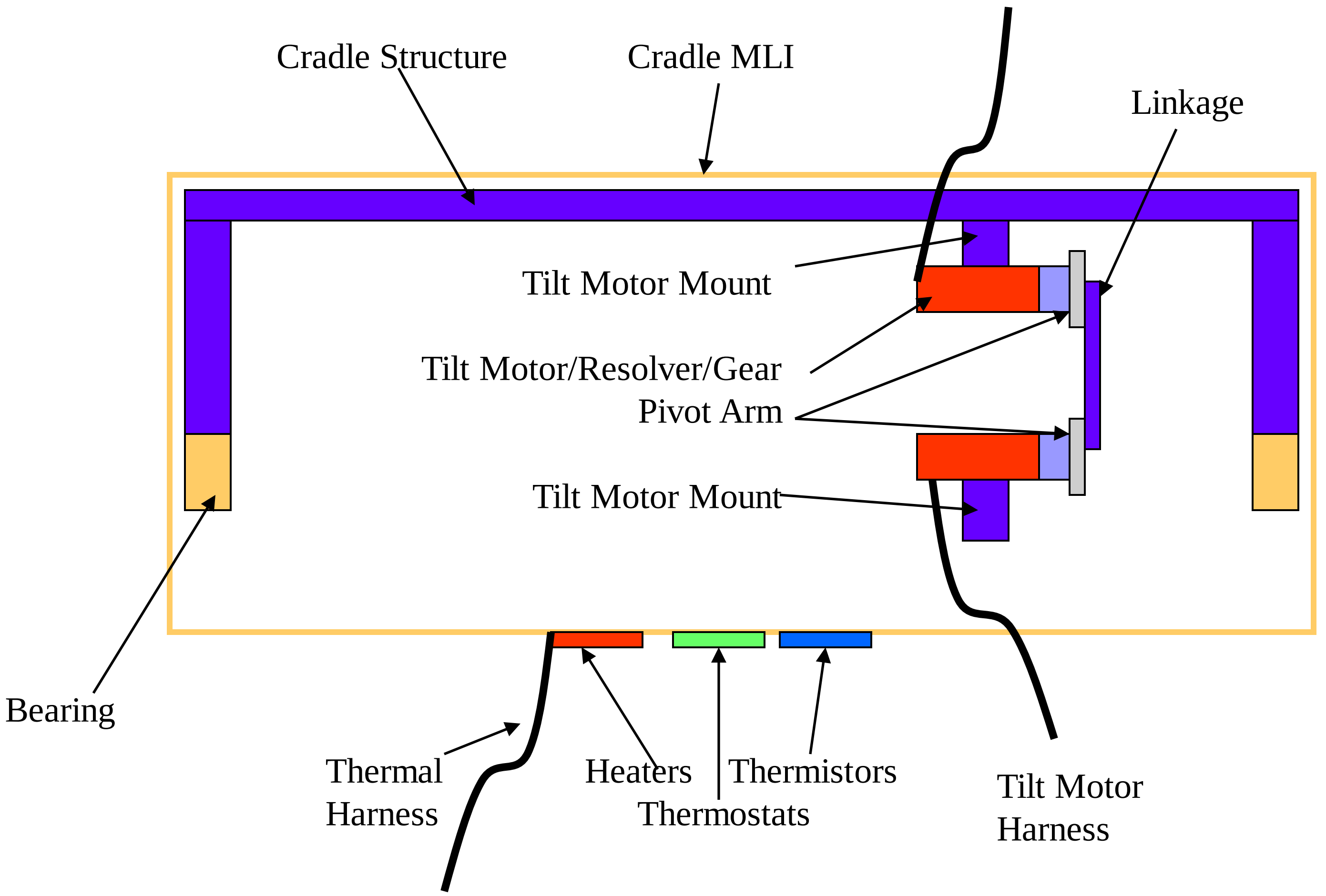


Cradle Assembly



Cradle Assembly Notional Block Diagram

Instrument Synthesis & Analysis Laboratory



Driving Design Requirements

Requirement	Design

Accommodate continuous scanning telescope	• 0.620 m telescope assembly
	  • Schmidt Plate
	  • Primary Mirror
	  • Fold Mirror
	  • Half Angle Mirror
	• Scanning Telescope Mechanism
	  • Brushless DC Motor w/ redundant windings and controller
	  • 135 rpm
	  • Inductosyn Resolver and R/D convertor
	  (±22.3 arcsec error budget on absolute position knowledge)
	  • 100% Duty Cycle
	• Half Angle Mirror Mechanism
	  • Brushless permanent magnet motor w/ redundant windings and controller
	  • 67.5 rpm, with control loop locking to telescope scan position
	  (±22.3 arcsec tolerance with respect to telescope primary position)
	  • Inductosyn Resolver and R/D convertor
	  • 100% Duty Cycle
	• Momentum Compensation Mechanism
	  • Brushless permanent magnet motor w/ redundant windings and controller
	  • 541 RPM
	  • 100% Duty Cycle

Effective Focal length (mm)	600
F/#	3.3
FOV	0.8 x 0.8
Wavelength range (nm)	350 - 2400
Pupil Diameter (mm)	180

Driving Design Requirements

Instrument Synthesis & Analysis Laboratory

Requirement	Design
96 Visible channels (5 nm spacing) between 350 nm and 830 nm at both 250 m and 1 km resolution	• Focal plane slits to provide 250m and 1 km along-track resolution • Gratings to provide 5 nm spectral resolution for the 1 km data • Prims to provide 5 nm spectral resolution for the 250 m data • Detection and readout via three Charged Coupled Device (CCD) arrays
Discrete channels in Visible, Near-Infrared, and Short-Wave Infrared at 250 m and 1 km resolution	• Light collected via fiber optics (69 fibers in total) at the focal plane. • Termination either via singlet/filter optics or proposed ball lens/filter technique • Detection and readout via photo-diode and FET amplifiers

Systems Summary
Part II

Top Level* Mass Summary
(no contingency included)

Ocean Color Experiment 3	Mass CBE (kg)	% of Total Mass
Scan Drum and Mechanism Assembly	54.9	19.7%
Scan Drum Assembly	40.3	14.4%
Half Angle Mirror Assembly	0.1	0.0%
Scan Drum Mechanism Assembly	2.7	1.0%
Half Angle Mirror Drive System	2.8	1.0%
Image Slicer/Slit Plate Assembly	0.1	0.0%
Calibration Target Assembly	9.0	3.2%
Momentum Compensator Assembly	31.8	11.4%
Cradle Assembly	32.1	11.5%
Cradle Structure	30.0	10.7%
Tilt Mechanism Assembly	2.1	0.7%
Aft Optics/Detector Assembly	54.9	19.7%
C-Channel	1.0	0.4%
1 Km Lens/Detector "Six Pack" Assembly	1.4	0.5%
1 Km Fiber Detector Assembly	2.4	0.9%
250 M Fibers Detector Array Assembly	5.5	2.0%
250 M Visible Channel	3.7	1.3%
1 Km Blue -Red Channel Assembly	5.2	1.8%
Structure	35.9	12.8%
Digitizer Box	11.3	4.0%
Main Electronics Box/ MEB	7.2	2.6%
Mechanism Control Electronics Box/ MCEB	8.2	2.9%
Purge and Venting	2.0	0.7%
Harness (length)	18.5	6.6%
Thermal Assembly	44.7	16.0%
5% misc Hardware	13.6	4.9%
Total (+ 5% hardware and no margin):	279.2	100.0%

*this listing does not include all subassemblies, please refer to the final mass model (MEL) for a full summary

Top Level Mass Summary by Subsystem *(no contingency included)*

Subsystem	Mass CBE (kg)	% of Total Mass
Contamination	2.0	0.7%
Detector	0.6	0.2%
Electrical	20.6	7.4%
Harness	18.5	6.6%
Mechanical	163.1	58.4%
Mechanism	8.07	2.9%
Optical	10.6	3.8%
Thermal	42.1	15.1%
5% misc Hardware	13.6	4.9%
Total (+ 5% hardware and no margin):	279.1	100.0%

Radiometry Summary

- **All the Ocean Channel SNR's were achieved**
  - Channel performance drivers were noted => 678nm and 710nm
  - The 820nm CCD channel could possibly be implemented as a fiber channel (SNR ~ 594)
    - This may help ease the spectrometer design
  - Could lose one grating array (1km) and still be 'close' in almost all channels
    - This could be pitched as a graceful degradation/failure scenario
  - L_{max} radiance is below the 750pe- CCD well capacity (26μm) => no detector saturation.
- **250m resolution spectrometer achieved**
  - SNR predicts are per the Oceans bands parameters (FWHM $\Delta\lambda$'s) except for the 763nm, 940nm, 1378nm and 2250nm.
  - This spectrometer does impact significantly the daily data downlink volume
  - Daily Data Volume*:
    - 1km spectrometer = 578 GBits
    - 250m spectrometer = 4.627 TBits
    - Fiber channels = 214 Gbits

    TOTAL: 5.4 Tbits

(*values corrected upward from those presented in Radiometry Presentation to account for 96 spectrometer channels)

- BTW, OCE-2 daily data volume (Qty. 144 - 1km fiber channels) = 420 GBits

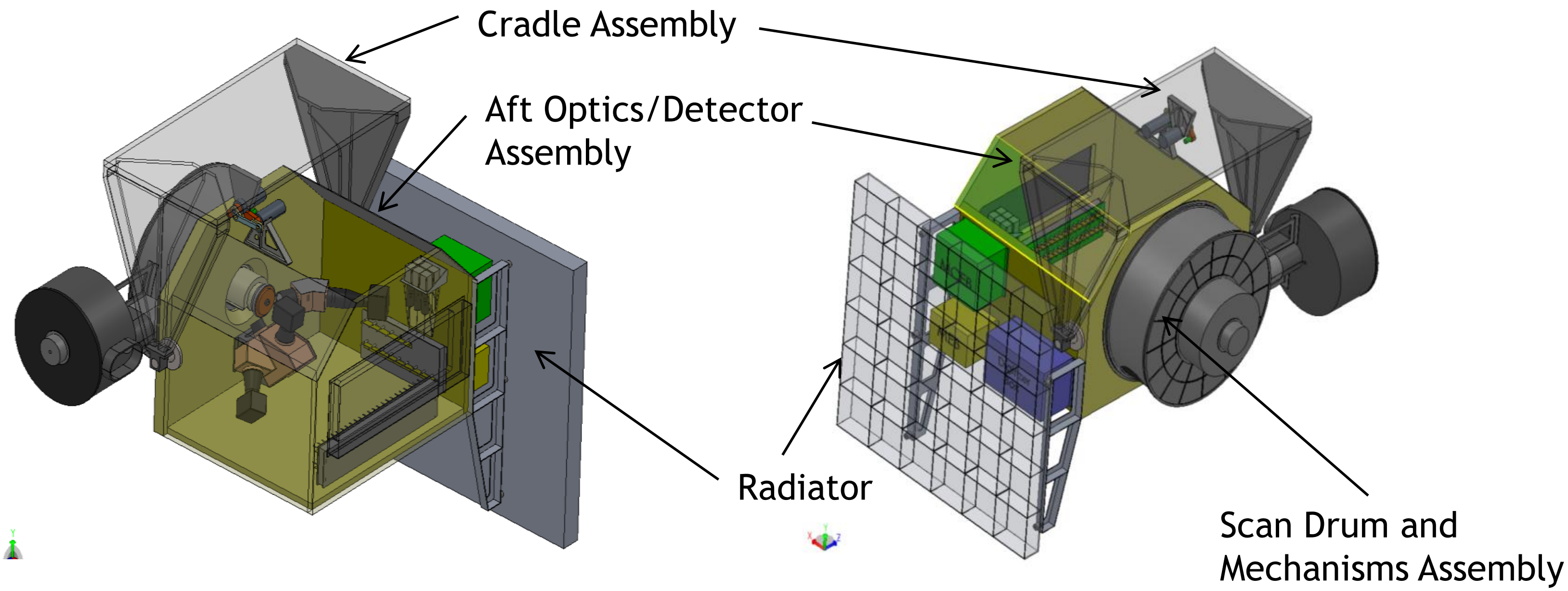
Optics Summary

Telescope designed altered slightly from the initial design to a longer focal length to accommodate the 700 km altitude for this study.

An image slicer, residing at the focal plane, splits the optical paths into a 1 km resolution blue arm(350 nm to 600 nm), a 1 km red arm (600 nm to 830 nm), a 250 m visible arm, and two fiber optic array bundles (200 micron and 800 micron cores) was developed to a conceptual level. The imager slicer remains a challenge, including challenges due to stray light.

The performance of the depolarizer may lead to either undesirable cross-talk (multiple images / "blur") or instrument polarizance (trade off). It is difficult to design a depolarizer that operates over such a large band-pass. The location of the depolarizer requires it to be very heavy. Ideally the depolarizer would be moved such that it can be smaller and lighter.

Mechanical Summary



Recommendations and Follow-on Work:

- Routing of fiber optics needs careful design effort to ensure integrity of fibers through launch
- Layout of Aft Optics
  - Layout currently in several planes which will increase difficulty of alignment
  - Mechanical design is credible but may need reinforcement to comply with strength and stiffness requirements
- Stiffness of Other Structural Components
  - Attachment of Calibration Mechanism to Scan Drum should be revisited
  - Cradle Assembly needs to be analyzed to ensure it provides adequate structural stiffness

Mechanisms Summary

All mechanism components on OCE3 (motors, resolvers) are unchanged from that proposed for OCE2:

Scan Tube, Half Angle Mirror, Momentum Compensator, Tilt Assembly, and Calibration Subassembly

Bearing life tests are not required:

Bearing life risk is greatly reduced from OCE2. **(Tammy - please check this).**

Mechanism lifecycle testing may be required per mission assurance.

Launch Locks are not recommended:

Further analysis during this OCE3 study confirmed that all bearings can accept launch loads.

FPGA modular firmware recommended for control and synchronization of telescope scan motor, half-angle mirror motor, and their synchronization.

FPGA use in this capacity on other flight programs is known.

Detectors Summary

OCE3 detection is achieved with a combination of charge coupled device (CCD) arrays and discrete PIN diodes of silicon and InGaAs varieties.

There are no technical issues or concerns in the detectors subsystem.

Custom CCDs readily available:

- These can be optimized for the wavelength ranges of interest

Both individual photodiode detector types are readily available from multiple vendors:

- Silicon: Hamamatsu, Pacific Semiconductors, Perkin Elmer, Code 553, etc., etc.
- InGaAs: Hamamatsu, Sensors Unlimited, Discovery Semiconductors

Several options are available for the fiber optic termination packages containing a filter, lens and photodiodes.

Electrical Summary

The OCE3 design requires three electrical box assemblies:

- Main Electronics Box (MEB)
- Mechanism Control Electronics Box (MCEB)
- Digitizer Electronics Box

Changes from OCE2 study were minimal:

MEB:

- Computer processor changed from Coldfire to BAE Rad750
- Added two CCD Control Boards for control of the three CCD arrays in the instrument aft assembly

Digitizer Box:

  - 9 SWIR boards
  - 2 CCD boards

MCEB:

- No changes from OCE2

Flight Software Summary

Line Of Code estimation shows 83% code reuse for MEB

- High heritage based on GSFC approach
- As noted in the software presentation, an implementation at another Center or at an experienced Vendor would take advantage of reuse algorithms, but the specific re-use percentage may differ
- No technical show-stoppers

Significant flight computational resources are needed If additional science data processing/reduction is to be implemented onboard (i.e. to reduce downlink bandwidth requirement)

- Processor platform to consider:
  - SpaceCube 2.0
  - Maestro 4x4

Contamination Control Summary

- **Construction in 10K cleanrooms required**
  - Standard practice for this type of instrument
    - Use Class 100 clean benches for Optics Subcomponents
  - Protection against molecular contamination
    - Hydrocarbons, silicones
    - Affects UVA and diffuser plates adversely
  - Protect against large particles
    - These block throughput and increase stray light
    - Redistribution likely after launch

- **Purge System Needed**
  - Mass for parts are accounted in MEL
  - Machined components for labyrinth vent traps needed

- **Computer analyses Recommended**
  - Similar to thermal analysis featuring View Factors
    - Calculate migration paths for molecules
    - Evaluate venting design

Thermal Summary

- **Fore telescope optics and aft optical arms are thermally isolated from the instrument structure.**
- **Two temperature control zones used for aft section / detector assemblies, each connected via dedicated heat pipe to a single, multi-sectioned, radiator on the cold side of the instrument**

Zone: +20 ± 1 C for CCD Arrays (3), SiPIN Photodiodes, FET pre-amplification, and switching

Zone: -20 ± 1 C for InGaAs Photodiodes, FET pre-amplification, and switching

- **Electronic Boxes (MEB, MCEB, and Digitizer Electronics) share a third thermal zone and reject heat, via a dedicated heat pipe, to the same radiator as detector assemblies.**

Reliability Summary

- **For OCE3, 3 Year Reliability is 83% for a selective redundancy design and 80% for a single string design**
  - Selective redundancy does not offer substantial improvements

- **Comparison with OCE2**
  - OCE2 Study showed 87% reliability for a select redundancy design and 71% for a single string design
  - Differences due to a higher fidelity of modeling for OCE3
  - Took advantage of more exposure to the IDL team and the customer team for higher fidelity modeling
  - The number of circuit boards modeled was refined to include redundancy only were needed
  - Built on previous research to increase fidelity of 100% duty cycled bearings

Recommended Future Work (1/2)

- **Optical Paths after the Focal Plane:**

The optical design provided to the OCE3 IDL team was adjusted (optical paths were moved: i.e. blue, red, and 250 m VIS arms) in order to accommodate placement of detection hardware. The impact of this modification should be revisited with the original optics designer.

- **Focal Plane Region Optics and Layout for Fiber Feeds:**

Design of optic fiber feeds with the 'fold mirror' in the image slicer assembly needs considerable design effort. Work presented here in this OCE3 study is more conceptual than design.

- **Spherical Optics Fiber Termination:**

There is confidence among the team that the spherical optics / filter termination concept is feasible. Since the team was unable to locate a realized example of this implementation, the technology readiness level must be assessed below '6'. If pursued, for flight, this technique would need an engineering demonstration.

Backup solutions are available, a commercial technique (with unknown internal components) or use of singlet optics and filter for all fiber terminations.

Recommended Future Work (2/2)

- **Data Rate, Data Storage, and Data Down-Link:**

If the large data rate, storage, or down-link is an issue, on-board processing by the instrument should be pursued. Capabilities of the RAD750 (used here) or more powerful computing hardware should be investigated. Processing would reduce the data rate through discarding un-useful data or through aggregation in spatial or wavelength dimensions.

- **Calibration Sub-Assembly**

Calibration sub-assembly presented here needs to be revisited with attention to overall size and mounting. Requirements for the calibration performance would be helpful and would be essential if a stray light analysis were performed for this sub-assembly.

Conclusions

Scan rate reduced to approximately 1/3 of previous (OCE2) study, increasing integration time and signal-to-noise ratio for all channels.

OCE3 pursued significant changes to the focal plane, optics, and detection methods techniques in the aft optics/detector region of the instrument. The spatial and wavelength resolution and SNR for the 350 nm to 830 nm and the NIR/SWIR channel are achievable with this design.

Remaining challenges:

- Further work needed on design of the fiber feeds in the image slicer assembly using the fold mirror technique.

- Further consideration, and perhaps demonstration assemblies, for the fiber termination options proposed here (i.e. ball lens concept).

- There are concerns that the size of the calibration subassembly presents structural issues for its mounting. Follow-on efforts should revisit the calibration assembly design, with and its mounting arrangement.

BACKUP CHARTS

Data Rate Calculation

OCE3 Orbit and Scanning Parameters:

700 km Altitude translates to 6.76 km/s ground speed

1 full scan (360 degrees rotation), 3.0 km ground translation per scan

0.44 sec / scan, scan assembly rate: 2.25 Hz / 135 rpm

1 km samples: 87.05 μs /sample (aka integration time)

+/- 51 degree imaging sector, 1473 samples per scan

250 m samples: 21.76 μs/sample (aka integration time)

+/- 51 degree imaging sector, 5892 samples per scan

Peak Data Rate:

1 km spectrometer data: 96 X (1 sample / 87.05 μs) X 6 slits X 14 bit = 92.64 Mbit/s

250 m prism data: 96 X (1 sample / 21.76 μs) X 12 slits X 14 bit = 741.18 Mbit/s

1 km fiber data: 7 X 3 X (1 sample/87.05 μs) X 14 bit = 3.38 Mbit/s

250 m fiber data: 4 X 12 X (1 sample / 21.76 μs) X 14 bit = 30.88 Mbit/s

Total = 868.7 Mbit/sec raw uncompressed

After compression (2:1) = 434.35 Mbit/s

With CCSDS Overhead (1.02) = 443.0 Mbit/s

Peak Data Rate = 443.0 Mbit/s

Average Data Rate:

Average Data Rate = (102/360) X (443.0 Mbit/s) = **125.5 Mbits/sec (Scan Average)**

Data Storage and Downlink Needs

Data Storage Needs per Orbit:
100 min x 60 s x 125.5 Mbit/s x 50% daylight = 376.5 Gbits / orbit

Date Storage Needs per Day:
24 hr x 3600 s x 125.5 Mbits/s x 50% daylight = 5.4 Tbits / day