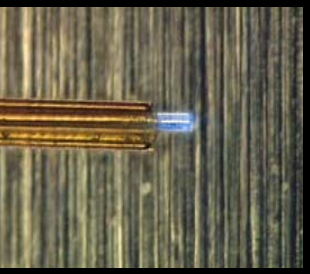
Space Flight Requirements for Fiber Optic Components; Qualification Testing and Lessons Learned



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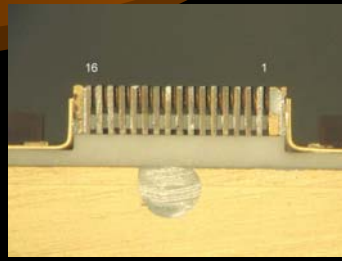
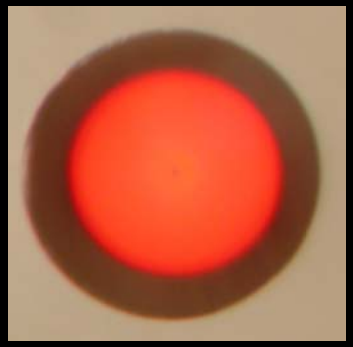
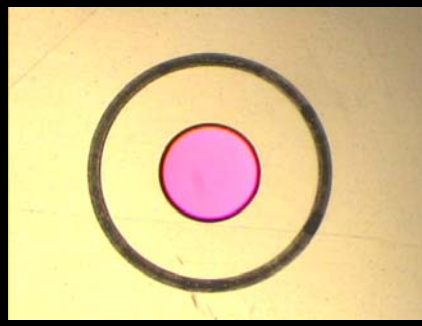






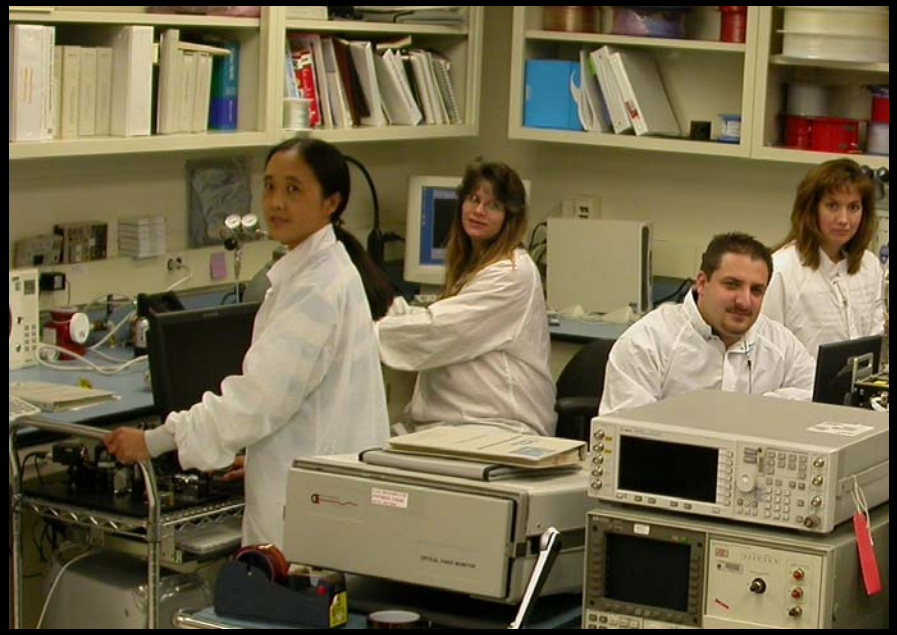
ESA/NASA Workshop 2006

Outline

- **Introduction**
- **NASA COTS Photonics Validation Approach**
- **Typical Environmental Requirements**
- **Mercury Laser Altimeter Test Results**
- **LRO – Laser Ranging Requirements**
- **Laser Ranging Pre qualification Test Data**
- **Lessons Learned-Manufacturing**
- **Conclusion**

Contributing Colleagues

The GSFC Code 562 Photonics Group & contributors



Photonics Group pictured left to right--
Dr. Xiaodan “Linda” Jin, Mary Malenab, Frank LaRocca
Patricia Friedberg, Richard Chuska, Shawn Macmurphy

Other collaborators not pictured:
Adam Matzuseski (Mech Lead LR) & Luis Ramos-Izquierdo (Optics Lead LR)

Introduction

Changes in Our GSFC Environment

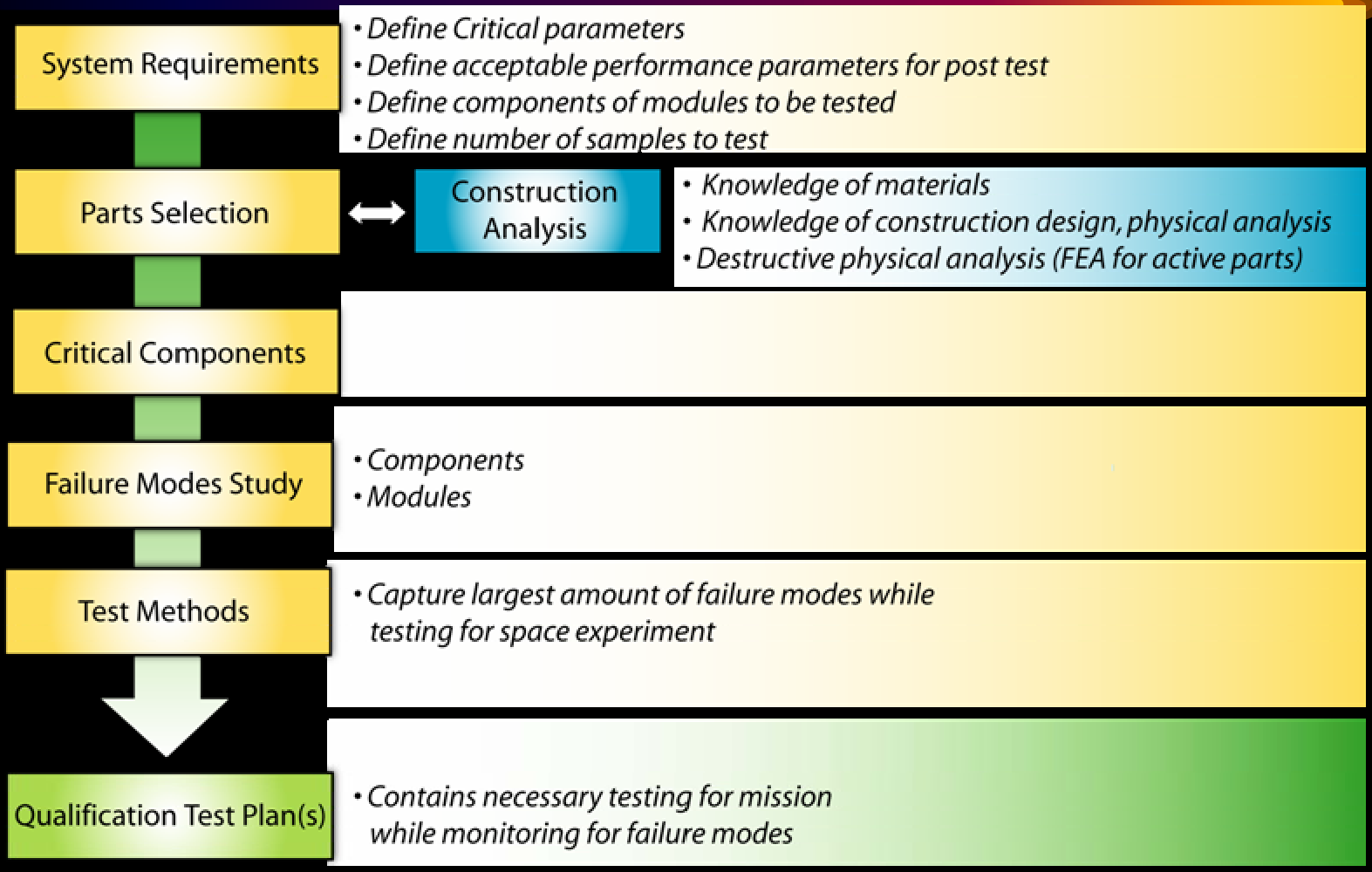
- Short term projects, low budgets
- Instruments like GLAS, MLA, VCL, LOLA

Changes to the Mil-Spec system, NASA relied heavily.
Telecommunications products available, state-of-the-art.
Vendors and parts rapidly changing.
Most photonics now COTS.
Qualification not only impossible but far too expensive.
Characterization of COTS for risk mitigation.
Quality by similarity where possible.

Issues to Consider

- Schedule, shorter term
- Funds available,
- Identify sensitive or high risk components.
- System design choices for risk reduction.
- Packaging choices for risk reduction.
- Quality by similarity means no changes to part or process.
- Qualify a “lot” by protoflight method—you fly the parts from the lot qualified, not the tested parts.
- Telcordia certification less likely now.
- Pre-qualification for high risk “unknowns”

COTS Technology Assurance Approach



Flow chart courtesy of Suzzanne Falvey, Northrup Grumman, based on M Ott reference:

* *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

COTS Space Flight "Qualification"

Materials Analysis	• Outgas testing for anything unknown • Take configuration into account
Vibration Survival and "Shock Test"	• Use components levels as defined by system requirements • Define parameters to monitor during testing
Thermal Cycling / Aging Test	• Define which parameters will indicate which failure mode • Monitor those parameters during testing
Radiation Testing	• Acclerated dose rate • Extrapolation model use if possible • Worst conditions
Additional Tests	• Based on specific mission requirements
Qualification Assurance Plan	• Continued reliable performance over life of mission

Flow chart courtesy of Suzzanne Falvey, Northrup Grumman, based on M. Ott reference:

* *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

Environmental Parameters

- Vacuum requirements
  - (Materials Analysis or Vacuum Test or both)
- Vibration requirements
- Thermal requirements
- Radiation requirements

Environmental Parameters: Vacuum

Vacuum outgassing requirements:

- ASTM-E595,
  - 100 to 300 milligrams of material
  - 125°C at 10^{-6} Torr for 24 hours
  - Criteria: 1) Total Mass Loss < 1%
    - 2) Collected Volatile Condensable Materials < 0.1%
  - Configuration test
  - Optics or laser nearby, is ASTM-E595 enough?
    - -ask your contamination expert

1) Use approved materials
2) Preprocess materials, vacuum, thermal
3) Decontaminate units: simple oven bake out, or vacuum?
4) Vacuum test when materials analysis is not conducted and depending on packaging and device.

Space environment; vacuum is actually 10^{-9} torr, best to test as close as possible for laser systems. Many chambers don't go below 10^{-7} torr.

Environmental Parameters: Vibration

Launch vehicle vibration levels for small subsystem (established for EO-1)

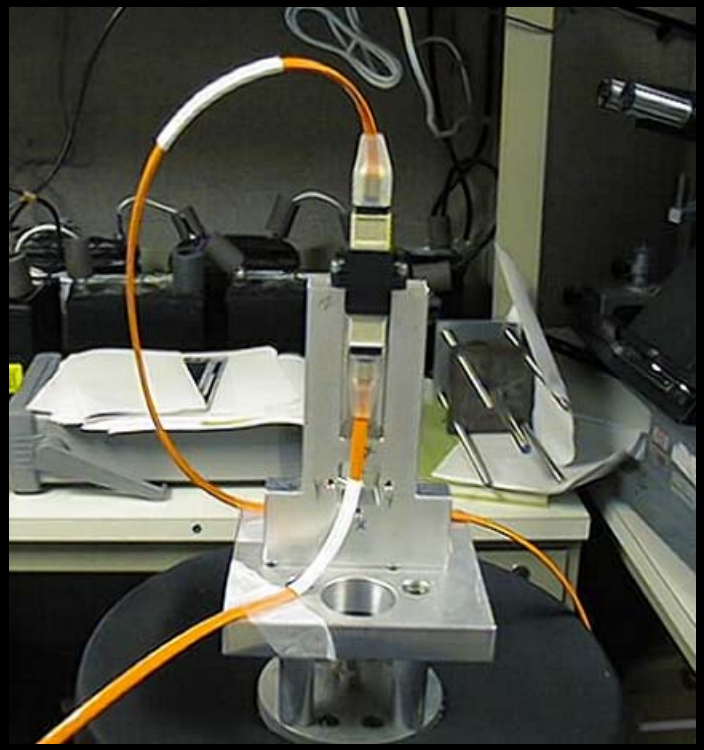
Frequency (Hz)	Protoflight Level
20	0.026 g^2/Hz
20-50	+6 dB/octave
50-800	0.16 g^2/Hz
800-2000	-6 dB/octave
2000	0.026 g^2/Hz
Overall	14.1 grms

However, this is at the box level, twice the protoflight vibration values establish the correct testing conditions for the small component.

Environmental Parameters: Vibration

Launch vehicle vibration levels for small component (based on box level established for EO-1) on the “high” side.

Frequency (Hz)	Protoflight Level
20	0.052 g^2/Hz
20-50	+6 dB/octave
50-800	0.32 g^2/Hz
800-2000	-6 dB/octave
2000	0.052 g^2/Hz
Overall	20.0 grms



3 minutes per axis, tested in x, y and z

Environmental Parameters: Thermal

There is no standard, typical and benign –25 to +85 C.
Telcordia is –45°C to +80°C.

Depending on the part for testing;

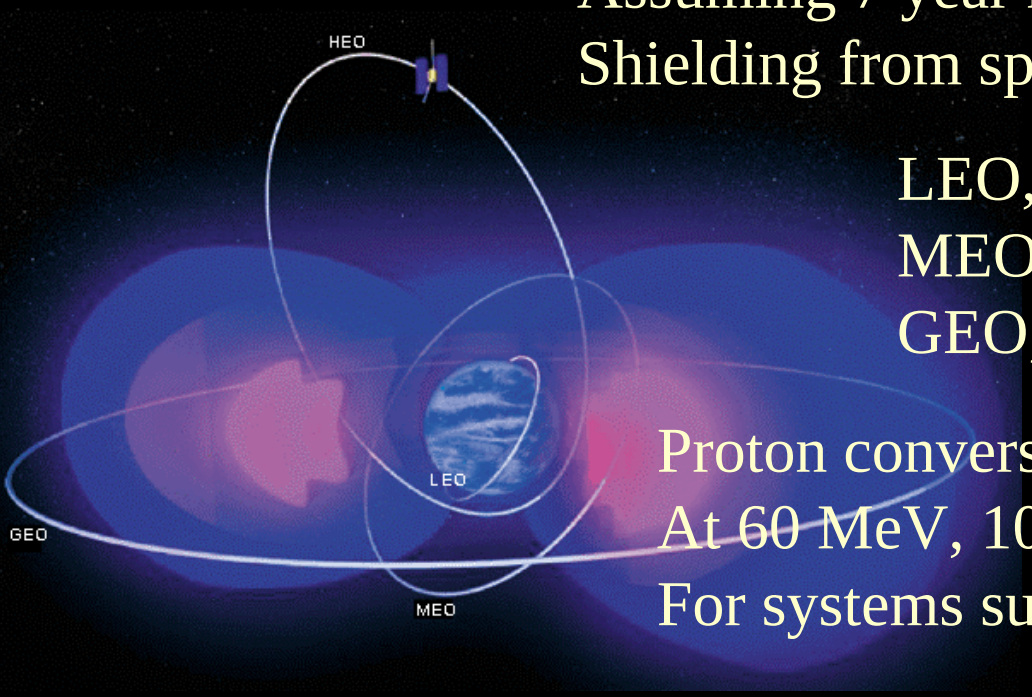
- Insitu testing where possible
- Add 10°C to each extreme for box level survival

Thermal cycles determined by part type

- 60 cycles for assemblies for high reliability
- 30 cycles minimum for assemblies, high risk
- 100 or more, optoelectronics.
- More for high power systems

Knowledge of packaging and failure modes really helps with determination of necessary thermal cycles

Environmental Parameters: Radiation



Assuming 7 year mission,
Shielding from space craft

LEO, 5 – 10 Krads, SAA
MEO, 10 –100 Krads, Van Allen belts
GEO, 50 Krads, Cosmic Rays

Proton conversion to Total Ionizing Dose (TID)
At 60 MeV, 10^{10} protons/Krad for silicon devices
For systems susceptible to displacement damage

Testing for displacement damage: 3 energies in the range ~ 10 to 200 MeV.
If you have to pick one or two energies stay in the mid range of 65 MeV and lower. Less probability of interaction at high energies.
Ballpark levels: 10^{-12} p/cm^2 LEO, 10^{-13} p/cm^2 GEO, 10^{-14} p/cm^2 for special missions (Jupiter).

Environmental Parameters: Radiation

Typical space flight background radiation total dose
30 Krads – 100 Krads over 5 to 10 year mission.

Dose rates for fiber components:

- GLAS, 100 Krads, 5 yr, .04 rads/min
- MLA, 30 Krads, 8 yr, .011 rads/min (five year ave)
- EO-1, 15Krads, 10 yr, .04 rads/min

Any other environmental parameters that need to be considered?
For example, radiation exposure at very cold temp, or prolonged extreme temperature exposure based on mission demands.

Mercury Laser Altimeter (MLA): Construction Analysis

Optical Fiber Assemblies

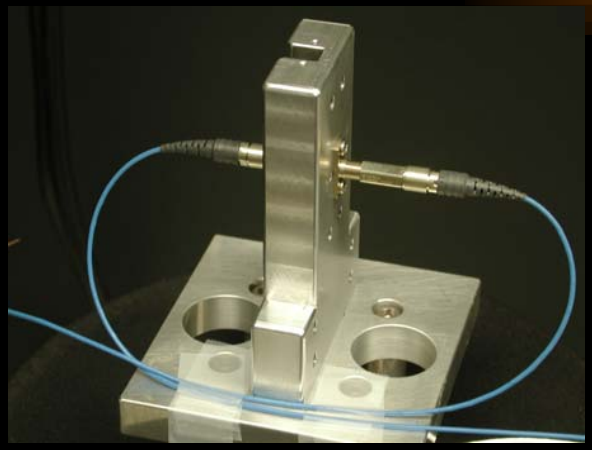
Diamond AVIMS connector / W.L. Gore Flexlite
Polymicro Technologies FIA 200/220
Performance: < 0.4 dB loss

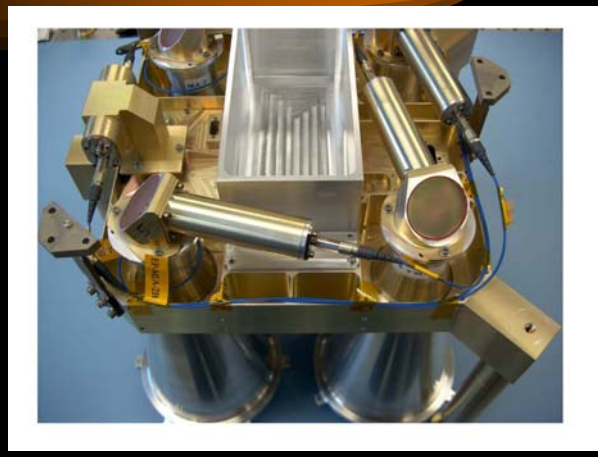
Preconditioning of non metallic materials and failure modes knowledge of construction

Hytrel boots: Thermal vacuum precondition: 140°C, 24 hrs, 1 Torr
Flexlite cable: Thermal preconditioning, 8 cycles, -20 to +60°C, 60 min at 60°C
Epotek 353ND: approved for space.

Post processing decontamination of assemblies @ 50°C (To bake out but not to age)
Cure schedule on outgassing database is very high temp.
Best to use close to usage temp cure, with a post cure bake out

MLA Assembly Environmental Validation





Requirements/Testing: Performance < .4 dB for all, 850 nm

Vibration 14.1 grms, 3 min/axis

Because box level @ 10 grms

Thermal: -30°C to +50 °C, 90 cycles, last 42 monitored

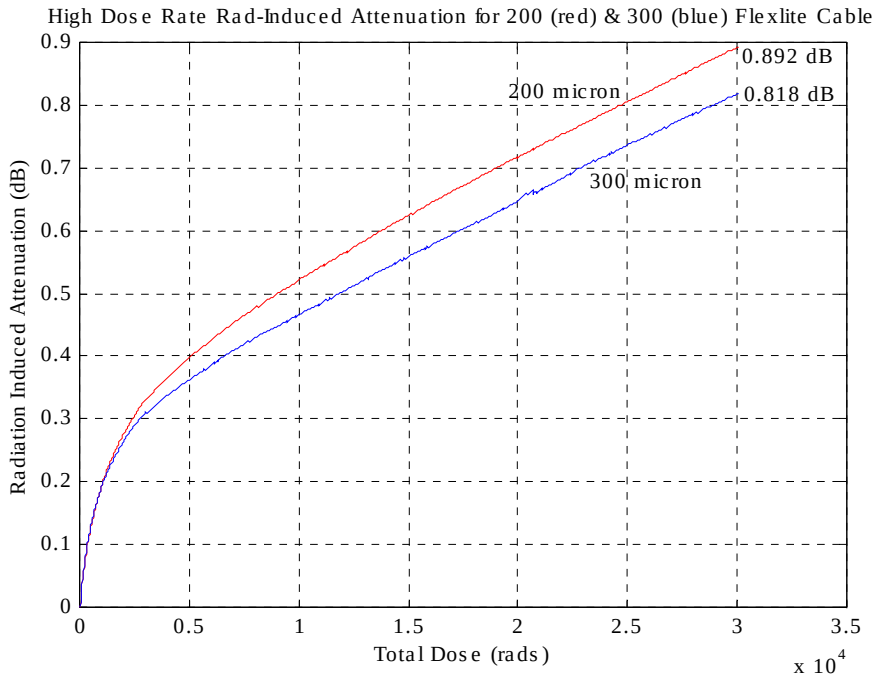
25 minute soak, 2 °C/min ramp rates.

Radiation: two dose rate model, -20°C,

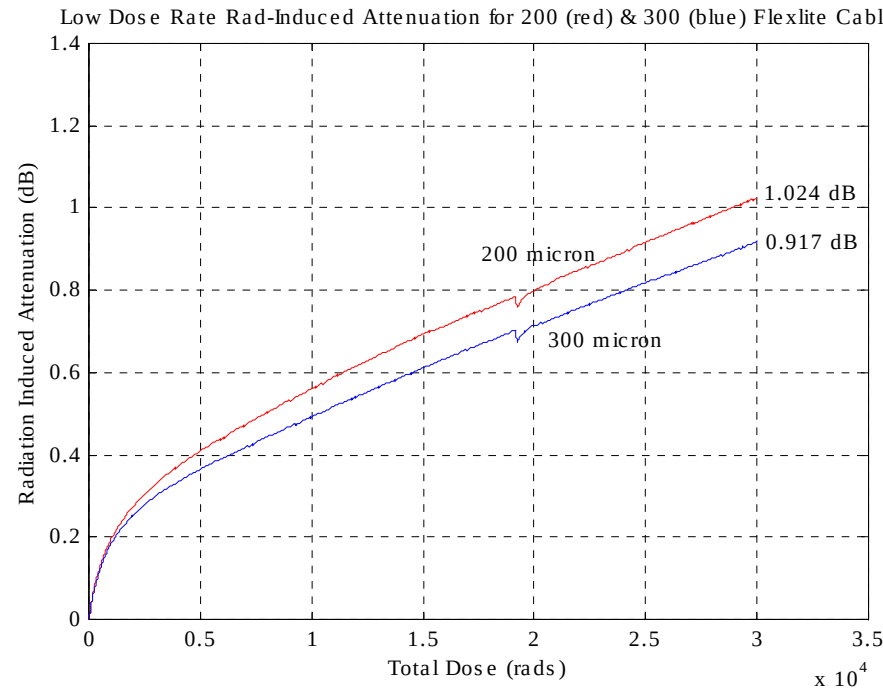
11.2 and 22.7 rads/min to 30 Krads

(Actual dose rate .011 rads/min)

MLA Assembly Environmental Validation



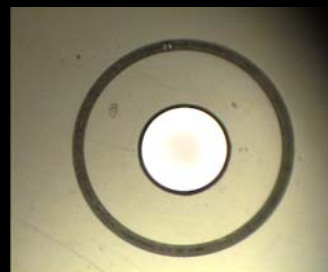
Flexlite Radiation Test, 22.7 rads/min at –18.3°C



Flexlite Radiation Test, 11.2 rads/min at –24.1°C

Radiation Conclusion: < .07 dB, using 11.2 rads/min, -24.1°C, 26.1 in, “dark”
Results for 10 m, at 30 Krads, -20°C, 850 nm, 23 rads/min ~ 1 dB or 0.10 dB/m

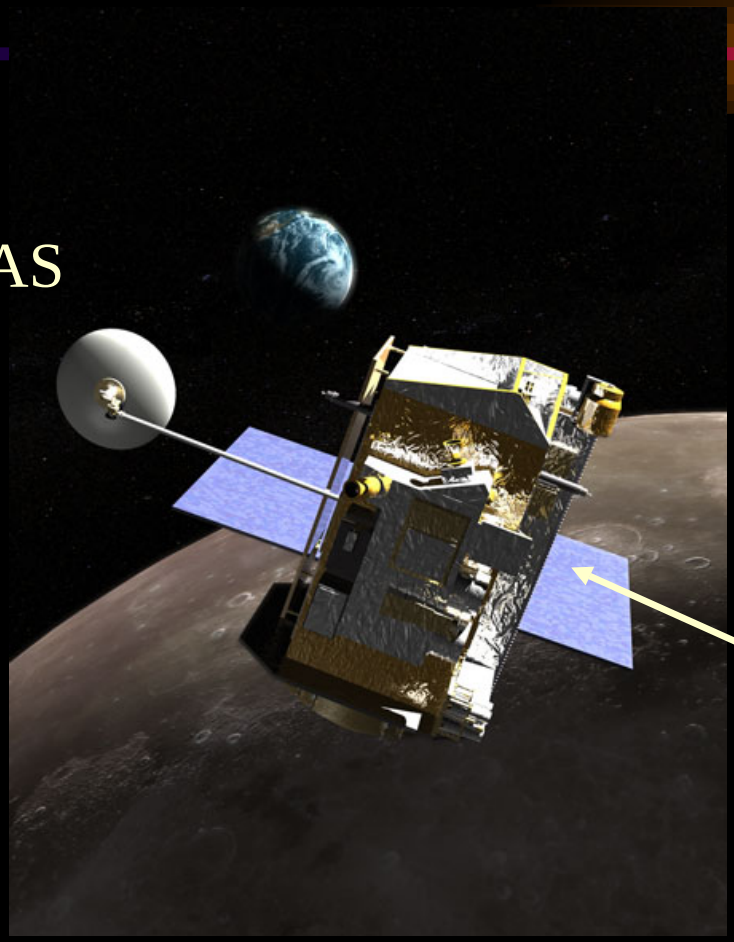
Random Vibration and Thermal Cycling: no registered losses
</= .04 dB power increase



Lunar Recon Orbiter : Laser Ranging and Altimetry

HGAS

Receiver Telescope mounted on HGA and a fiber array to route signal from HGA to LOLA



Lunar Orbiter Laser Altimeter LOLA

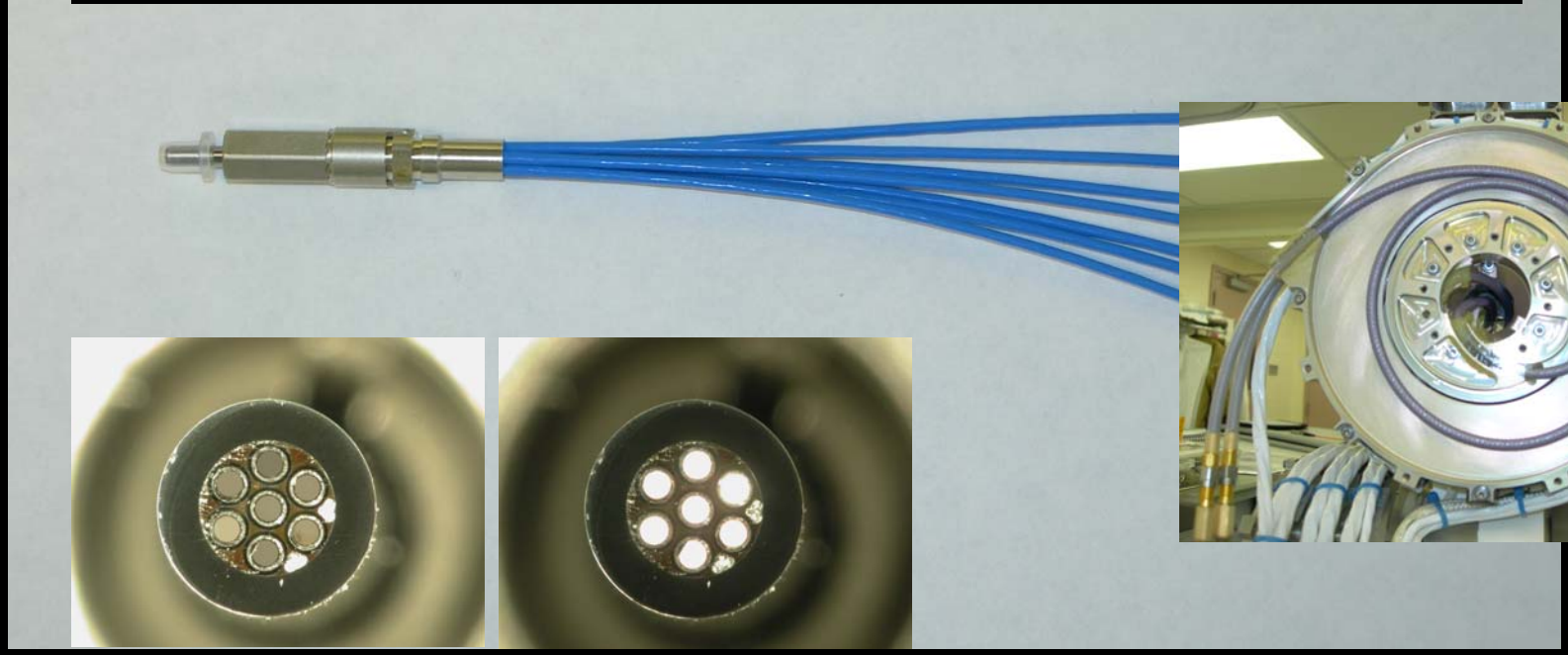
Deployable HGA will move in x and y via gimbals
Fiber bundle will be routed through gimbals, down boom and to LOLA
Issues: Cold temperature during gimbal movement, low loss requirements

Laser Ranging Requirements

- Receiver optics system fiber bundle array
- 10 m max length of assembly
- 7 fiber bundle from receiver telescope to LOLA, single connector
- Some sections will receive nearly 1 Mrad while cold.
- Budget is 2 dB for all losses including environmental and performance.
- Data from MLA not enough for rad performance extrapolation.

GSFC Optical Fiber Arrays

AVIM connectors with custom drilling (single hole, not LR design) with 300/330 optical fiber Flexlite cable

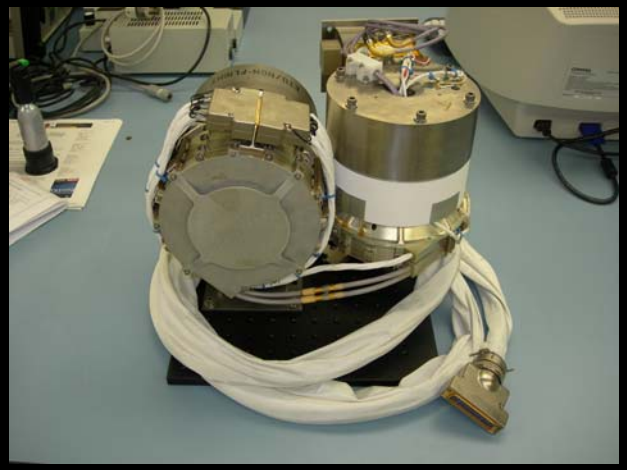


Outgas Testing to ASTM-E595

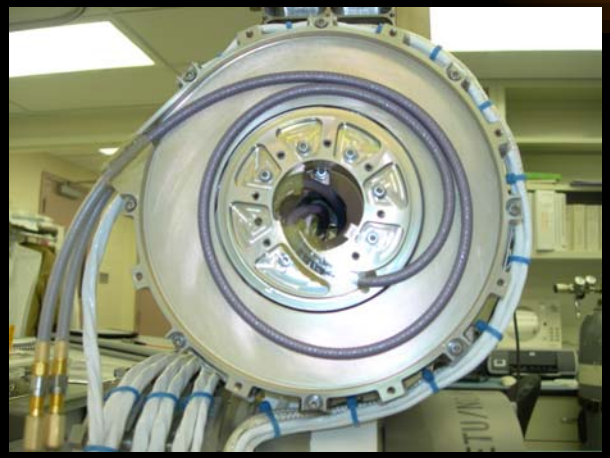
Diamond AVIMs Right Angle Boot; TML 0.01%, CVCM 0.00%

W.L. Gore Outer Jacket PFA for over metal braid; TML 0.01%, CVCM 0.00%

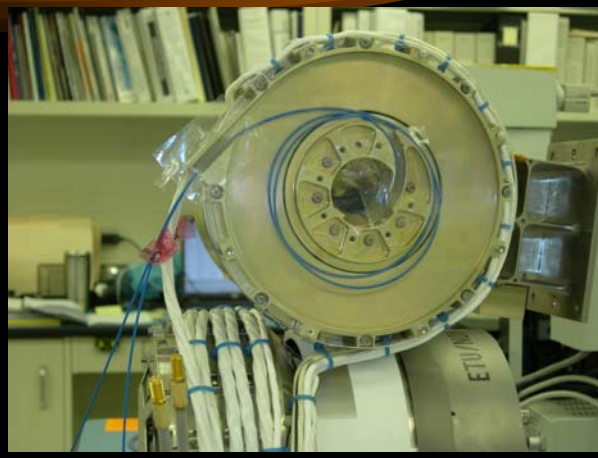
LRO Ranging Pre-Qualification Test



Gimbals



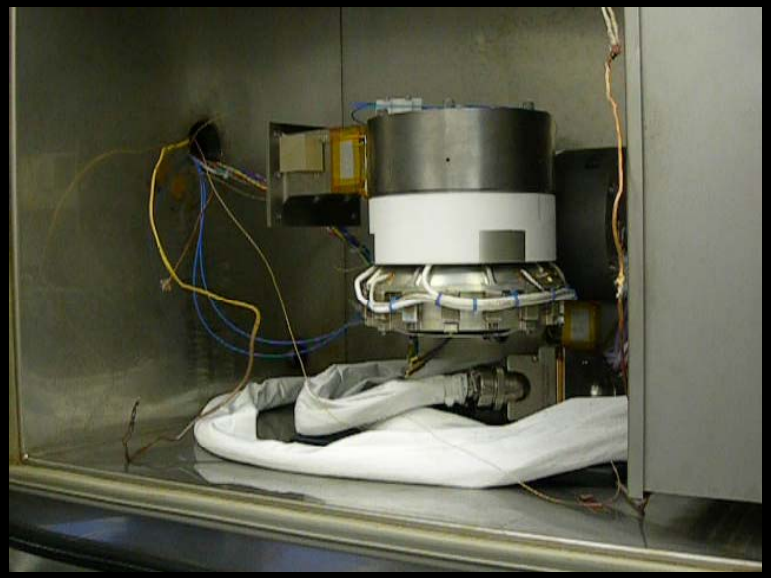
Window inside gimbal; RF cable wrap



Window inside gimbal; Flexlite MLA cable wrap inside gimbal

Fiber optic cable (4 m) gimbal test inside of thermal chamber monitored in situ @ 850 nm

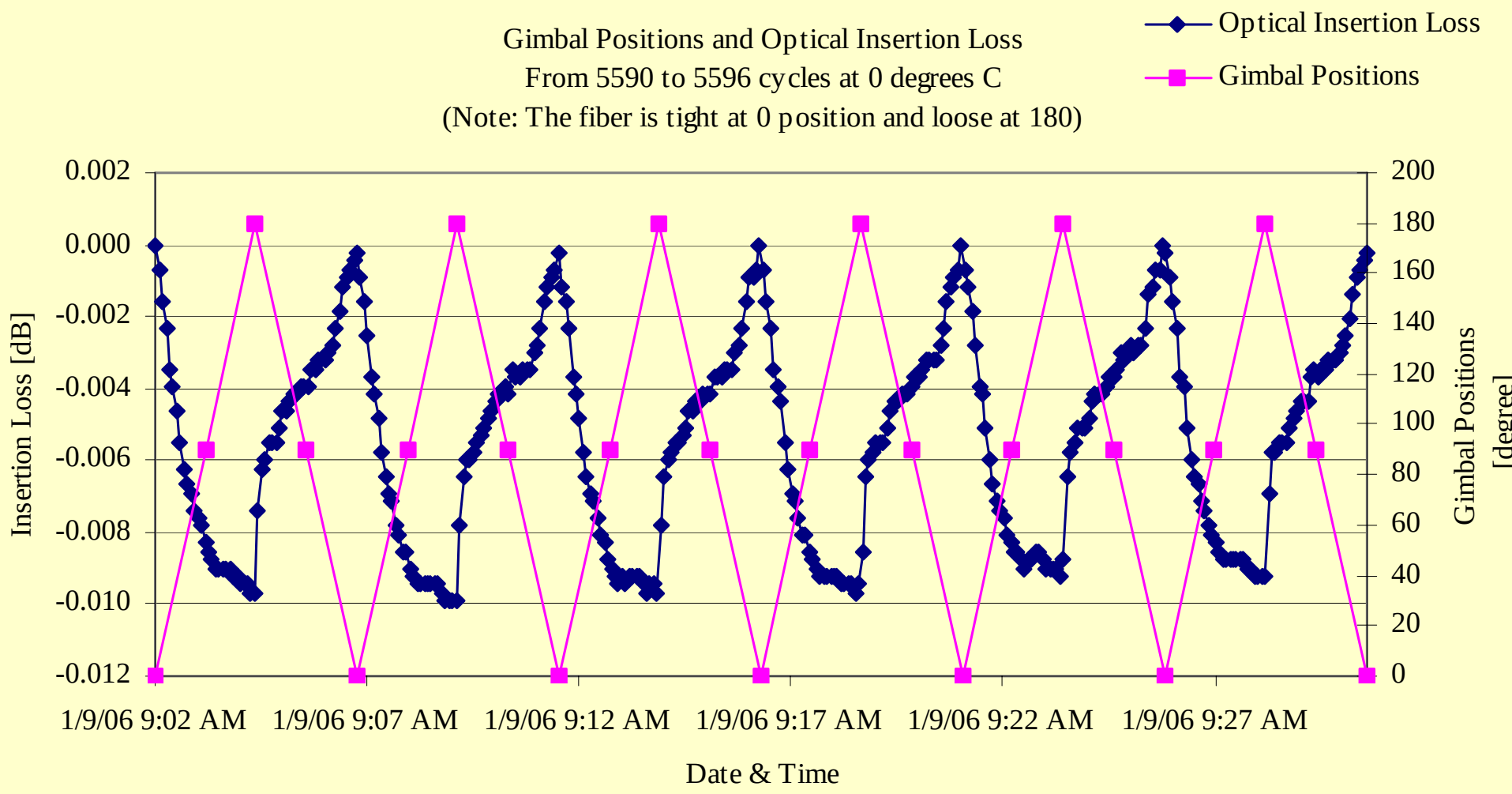
Each gimbal cycle up and back is 4 min 45 sec



Cable wrapped through twice, in constant motion to 5000 cycles per temp for 3 temps; 0°C, -10°C and -20°C

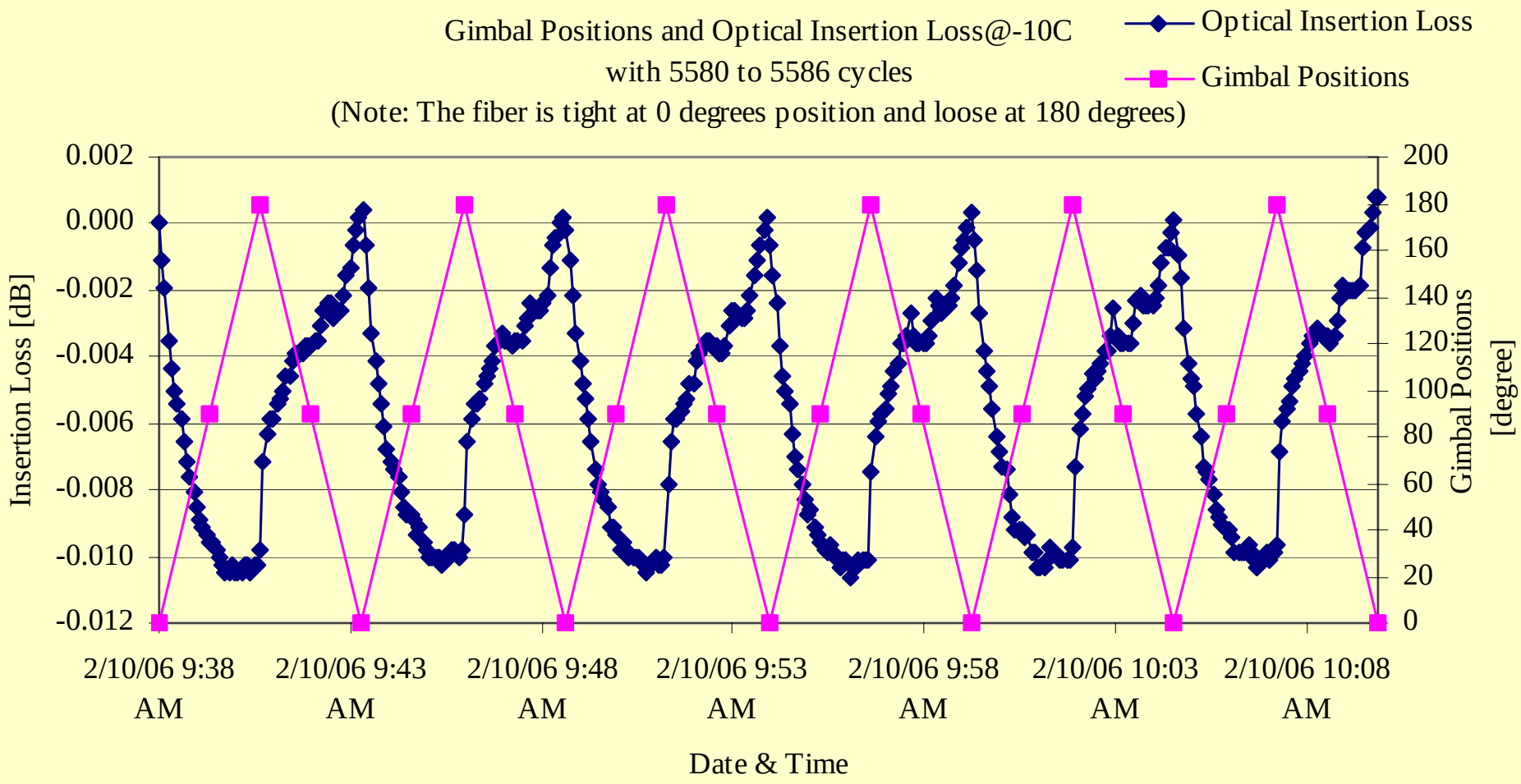
LRO Ranging and Altimetry Gimbal Test

Results of Test 1 at 0°C, Last few gimbal cycles, flex losses < 0.010 dB



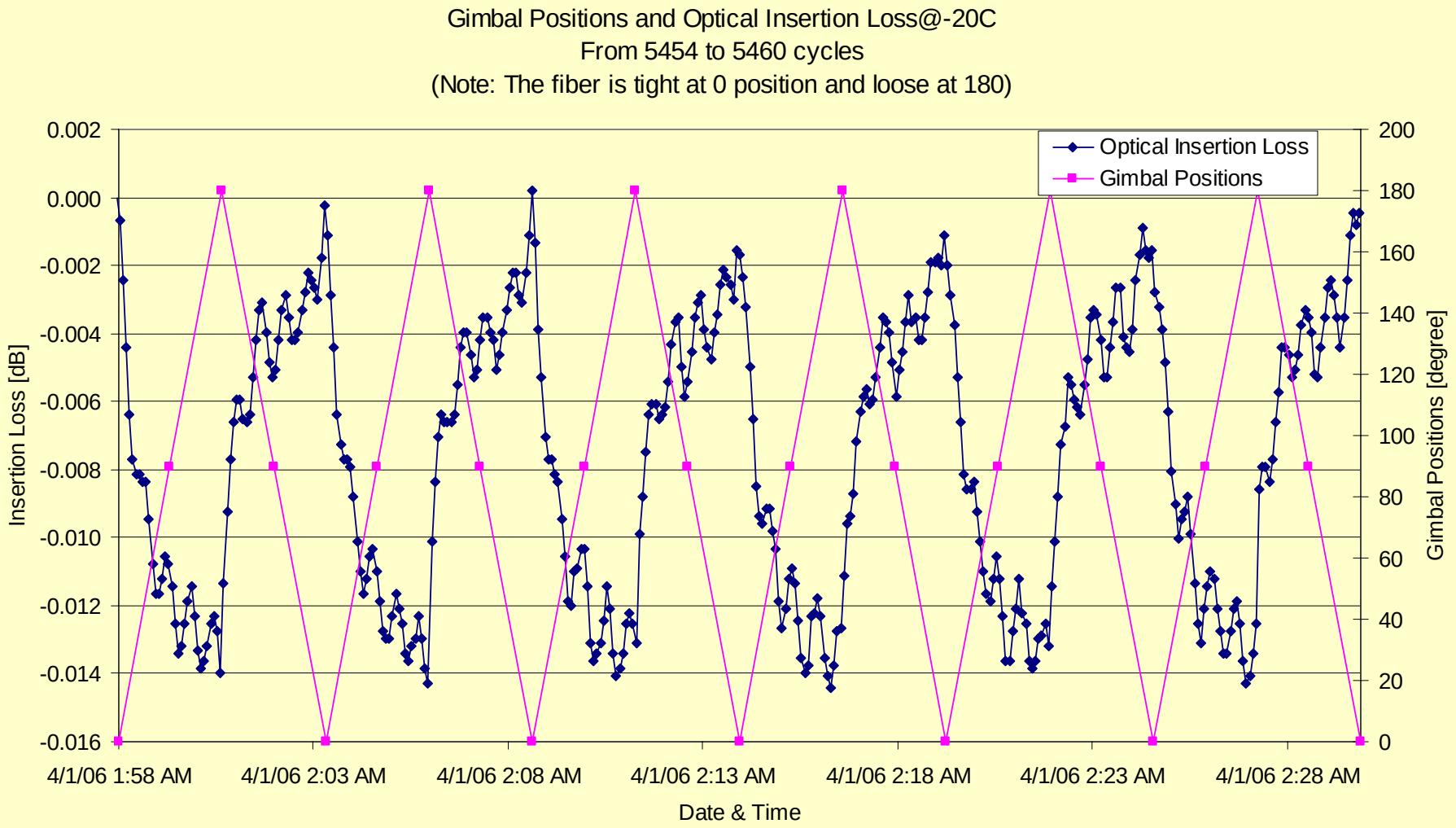
LRO Ranging and Altimetry Test

Results of Test 2 at -10°C, Last few gimbal cycles, flex losses < 0.012 dB

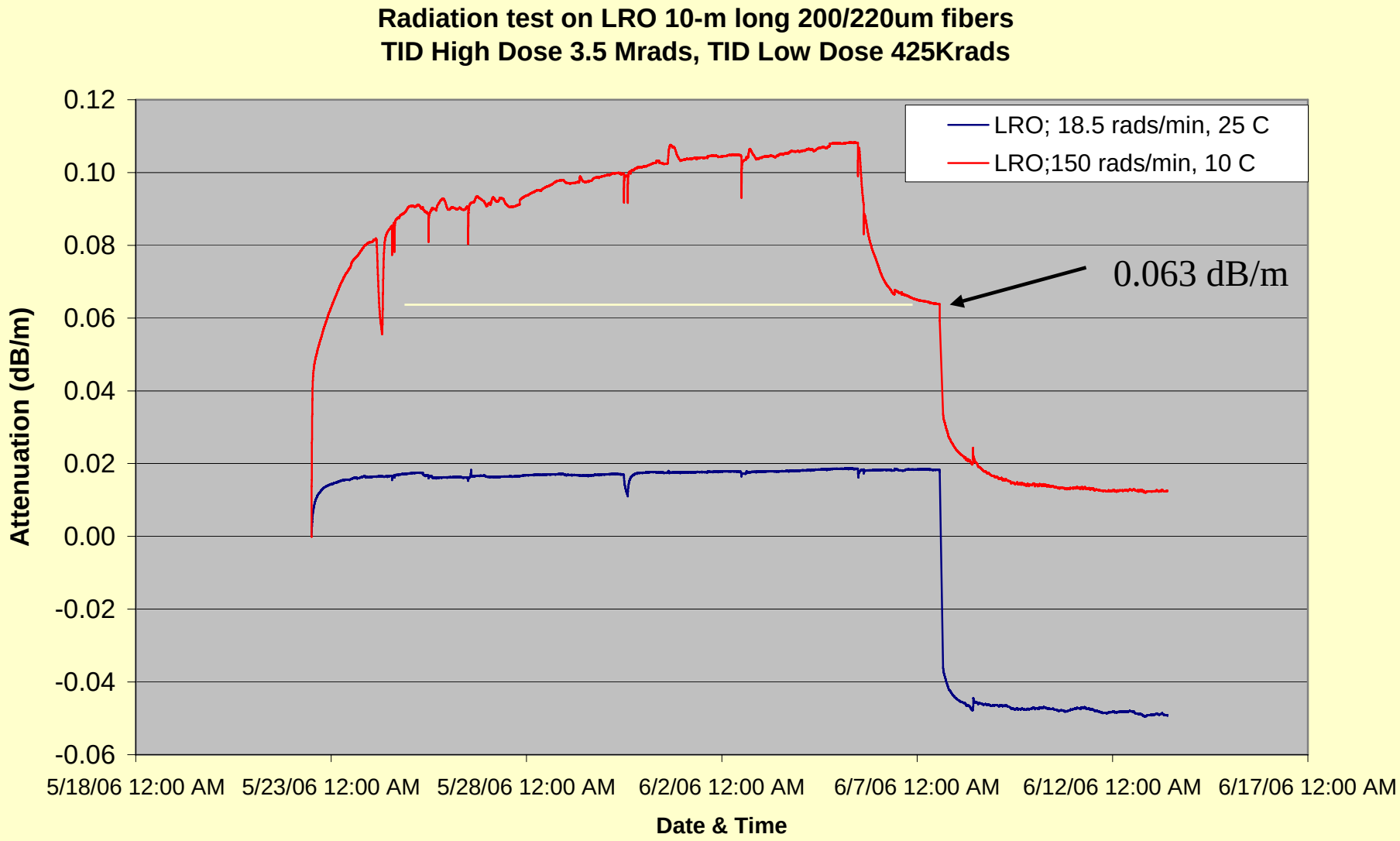


LRO Ranging and Altimetry Test

Results of Test 3 at -20°C, Last few gimbal cycles, flex losses =< 0.014 dB



Laser Ranging Radiation Prequal Test Results



Hytrel Diamond AVIMs boots- beyond 1 Mrad no changes visible.

Lessons Learned - Terminations

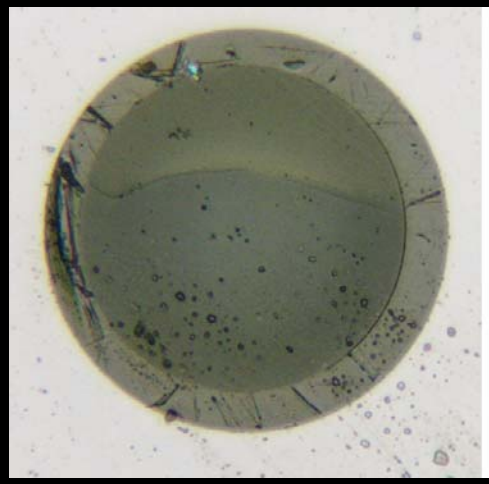
Epoxy curing schedules for space flight applications

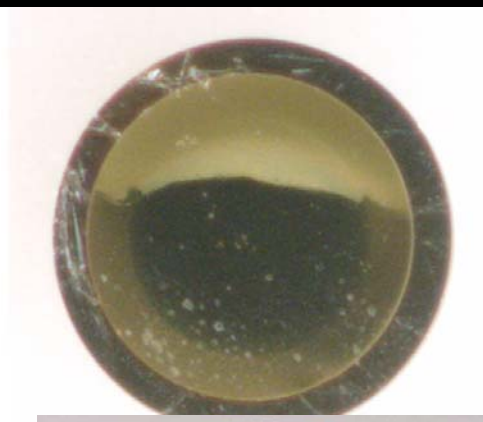
If too high a cure temperature is used for terminations
Failures can occur if the operation temperature of application is low

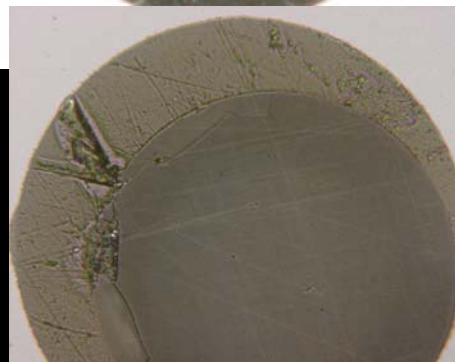
Germanium doped graded index multimode is very sensitive to stress induced cracking such as CTE.

Germanium doped graded index

- Atomic structure stress
- Concentration higher at core—CTE differences along cross section.
- Micro-cracks exist, internal structure and manufacturing.







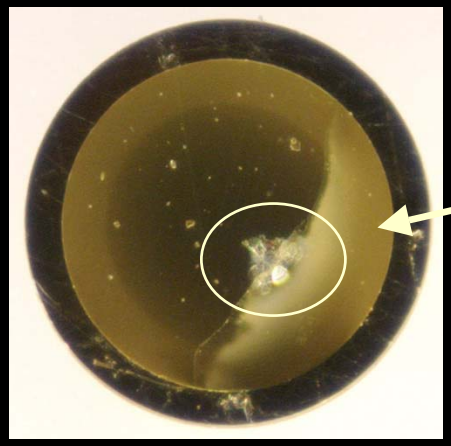
Lessons Learned -Terminations

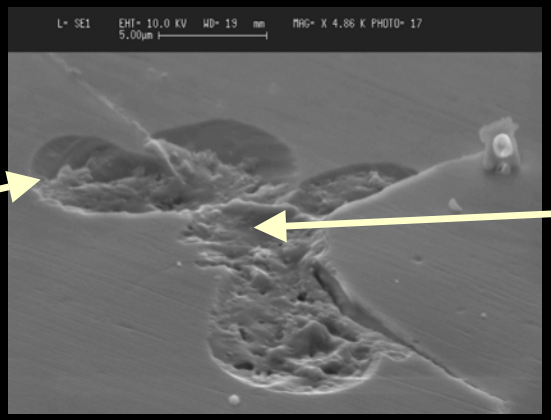
Polishing Processes

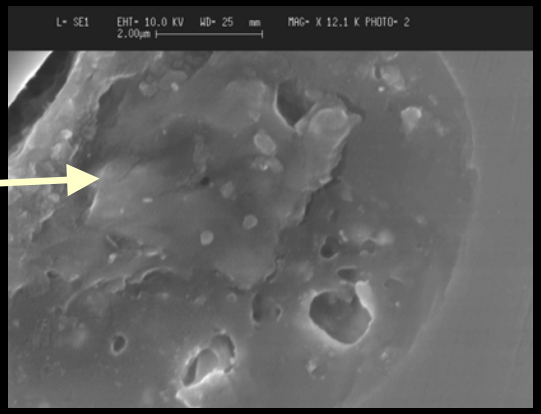
GSFC uses nothing larger than 5 micron lapping film.
Using too high of a grit on the lapping film can set up latent cracks.

Inspection and Cleaning

GSFC uses 200 X final inspection.
For especially Ge-doped Graded index fiber, avoid contamination







SEM images of contamination – Corrosion on fiber end face

Conclusion

"Qualification and Issues with Space Flight Laser Systems and Components" M. Ott, D. B. Coyle, J. Canham, H. Leidecker, Jan 26, 2006 SPIE Photonics West, Vol. 6100.

"Space Flight Requirements for Fiber Optic Components; Qualification Testing and Lessons Learned," Photonics Group, April 2006, SPIE Europe Vol. 6193

SPIE Optics and Photonics session on Photonics for Space Environments XI
To be presented in San Diego USA, Aug 2006.

- Current Activities in the Photonics Group
- Qualification of MTP and Ribbon Cable Assemblies for Space

Thank you for your attention.

For more information please visit the website:

misspiggy.gsfc.nasa.gov/photonics

NASA GSFC Code 562 Photonics Group