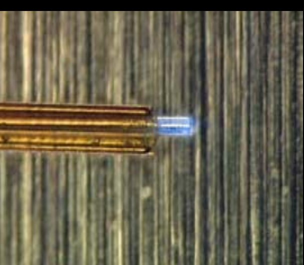


Space Flight Requirements for Fiber Optic Components; Qualification Testing and Lessons Learned



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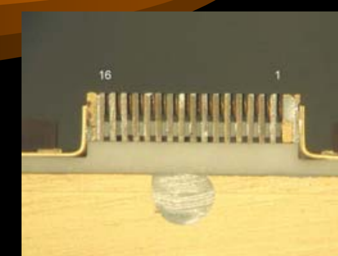
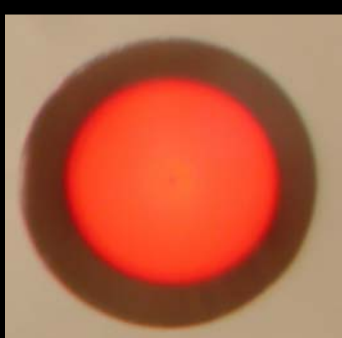
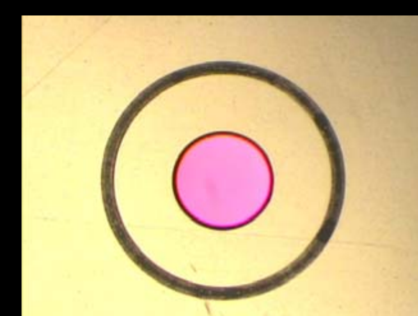






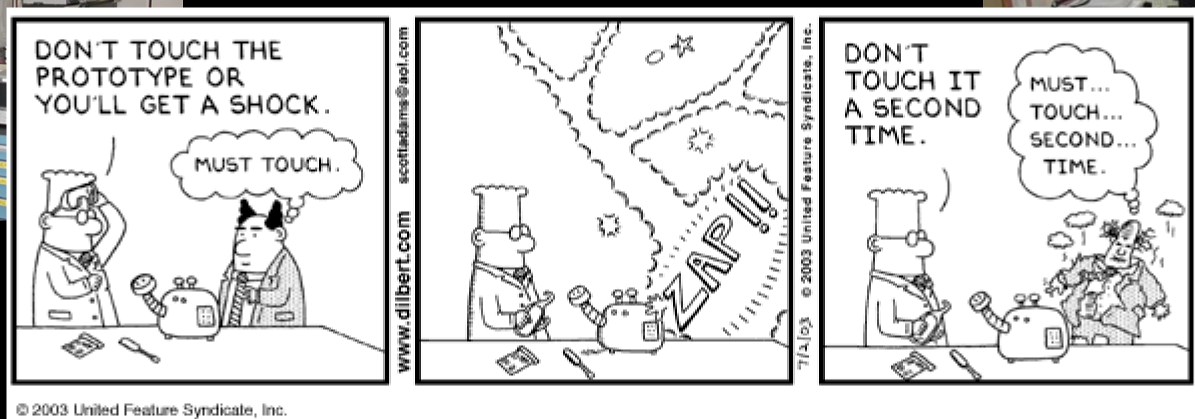
Reliability of Optical Fiber Components, Devices, Systems and Networks III, Conf. 6193

Outline

- Introduction
- NASA COTS Photonics Validation Approach
- Construction Analysis
- Vacuum Validation
- Vibration Parameters
- Thermal Parameters
- Radiation Parameters
- Lessons Learned-Manufacturing
- Prequal Example: LRO
- Conclusion

Contributing Colleagues

Code 562: Parts, Packaging, & Assembly Technologies Branch



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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.

COTS Technology Assurance Approach For Space Flight

System Requirements (Instrument System Engineer) : Define critical component parameters and the quantity by how each can deviate from optimal performance as a result and during testing -- Performance requirements.

Environmental Requirements (Mechanical, Thermal, Radiation Engineers)

Contamination and materials requirements.
Box level random vibration, double for component
Thermal environment, 10 C higher at extremes
Radiation, worst case conditions.

Failure Modes Study, (Components Engineer)

- Conditions and Parameters,

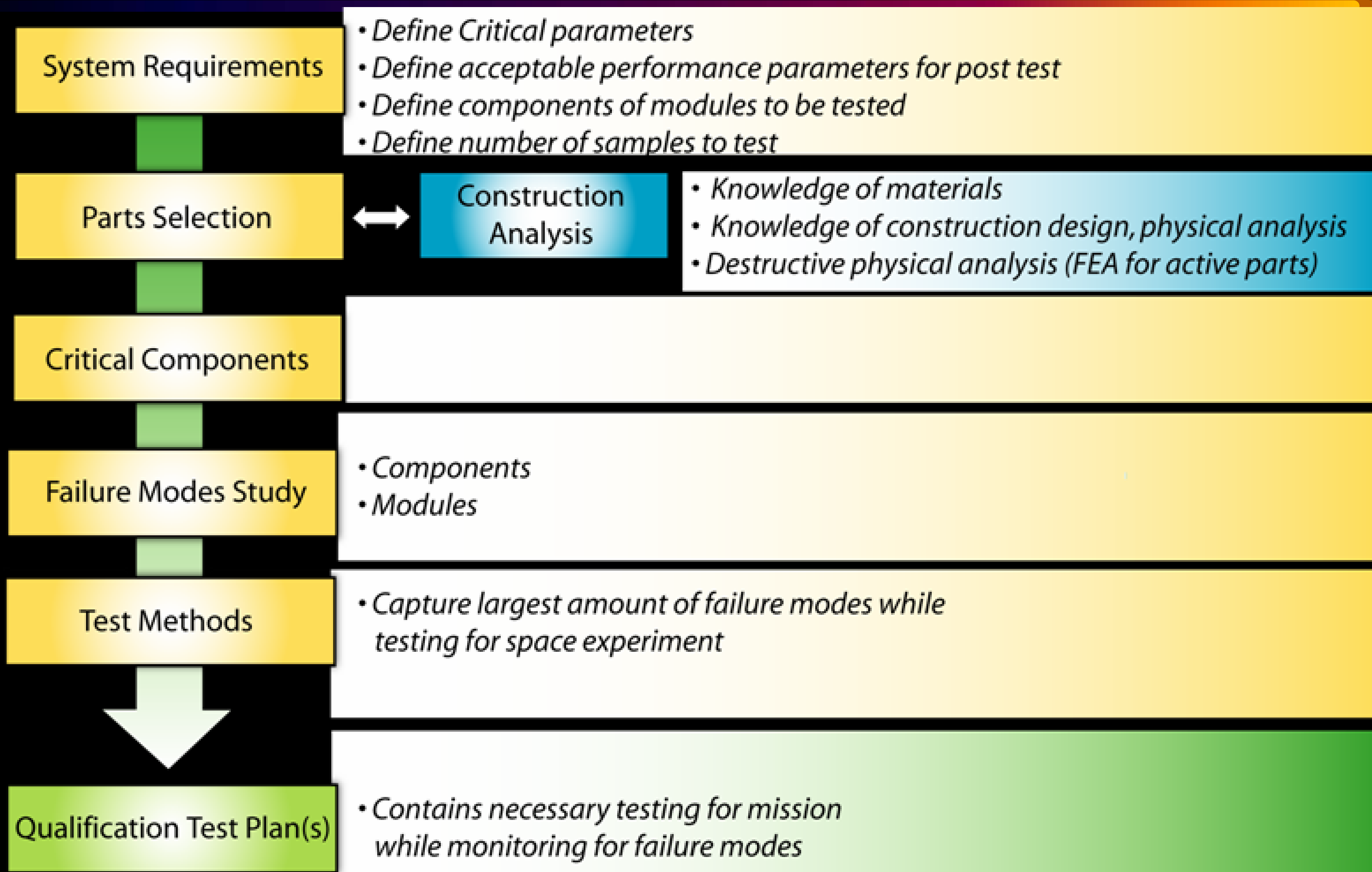
Test Methods

- Tailored to capturing the largest amount of failure modes while testing for space environment.

Test Plan

- Contains necessary testing for mission while monitoring for failure modes.

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.

Qualification Plan

Define critical parameters that must be stable during testing.

Define acceptable changes in performance parameters as a final result of testing and testing (dynamic and permanent). Acceptance criteria

Choose parts or system to be tested.

How many samples (sample size) can you afford to test (considering time, equipment, materials)?

Materials Analysis,

- Outgas testing for anything unknown, take configuration into account.
- Packaging!
- Destructive Physical Analysis is crucial to formulation of testing plan

Vibration Survival and “Shock” (larger components) Test

- Use component levels as defined by system requirements
- Define parameters to monitor during testing

Thermal Cycling/Aging Test or Thermal Vacuum (depends on materials analysis)

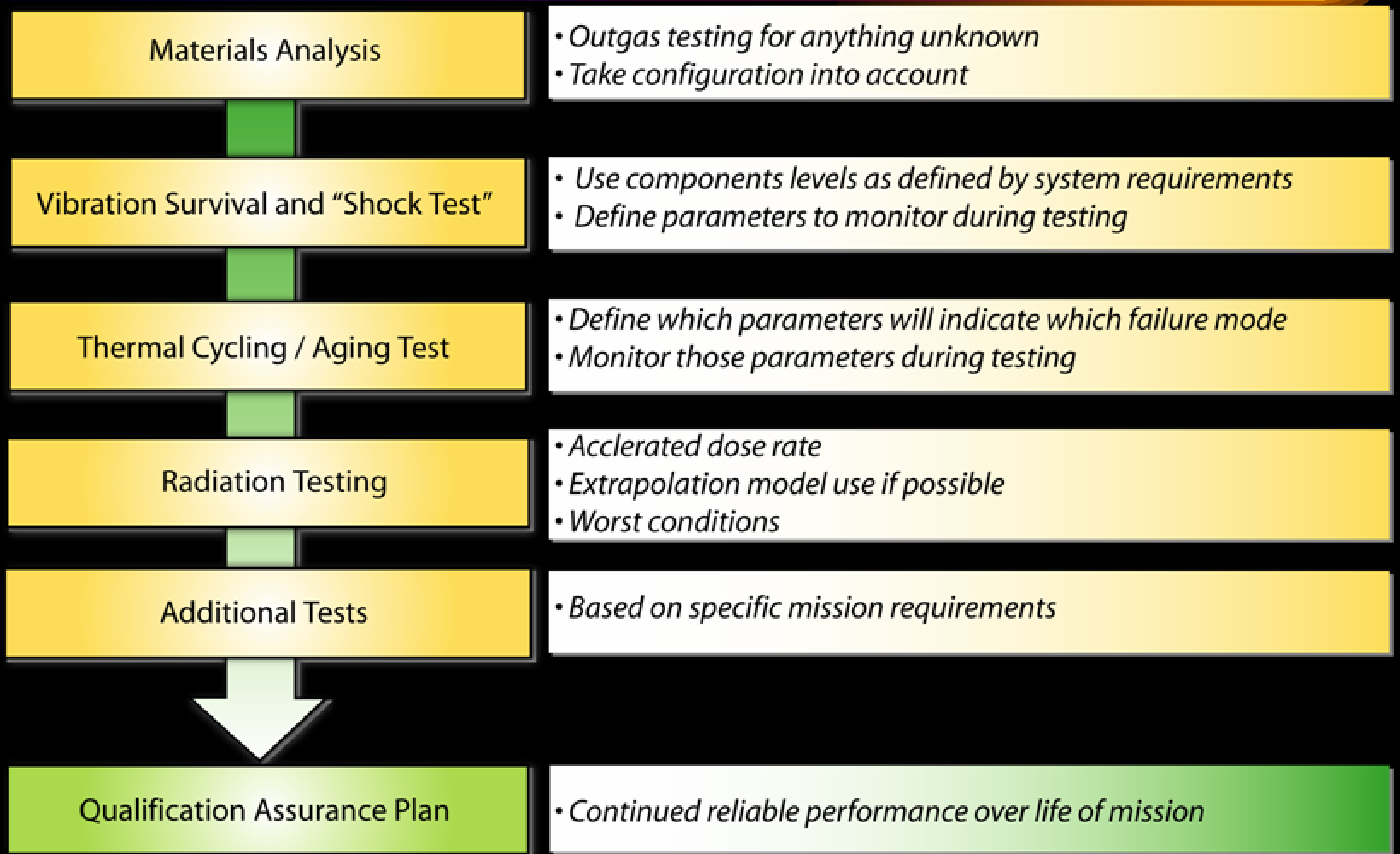
- Define which parameters will indicate which failure mode
- Monitor those parameters during testing.

Radiation Testing

- Accelerated dose rate, extrapolation model use if possible, worst conditions

Addition tests based on specific mission requirements?

COTS Space Flight "Qualification"



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Construction/Materials Analysis

Destructive Physical Analysis
- Identify packaging issues

Gases analysis, hermetic?

Materials identification,
- Packaging: wirebonds, die attach materials

Identify non metallic materials for vacuum exposure
- Potential contamination issues.

Construction Analysis is crucial!
- Long Term Reliability
- Will it survive harsh environments?

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)

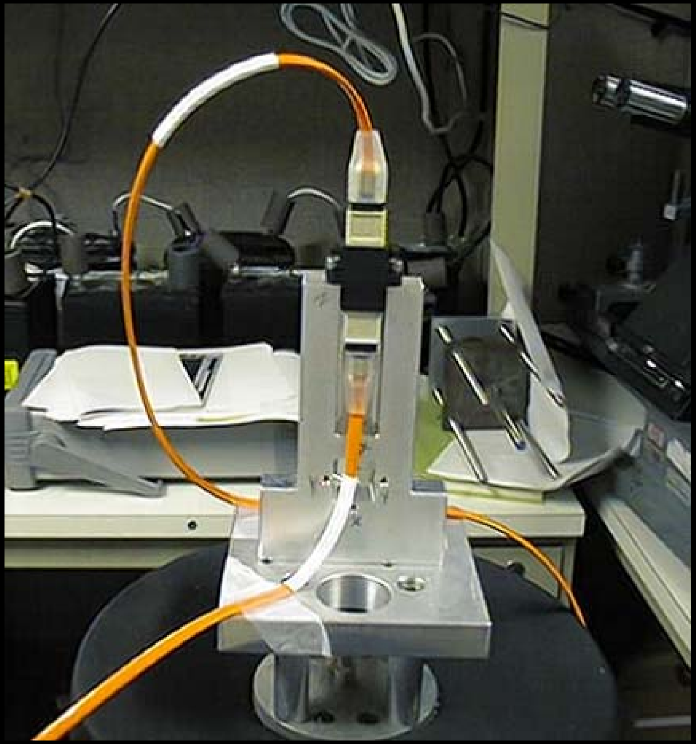
Frequency (Hz)	Protoflight Level
20	0.026 g^2/Hz
20-50	+6 dB/octave
50-800	0.16 g^2/Hz
800-2000	-6 dB/octave
2000	0.026 g^2/Hz
Overall	14.1 grms

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

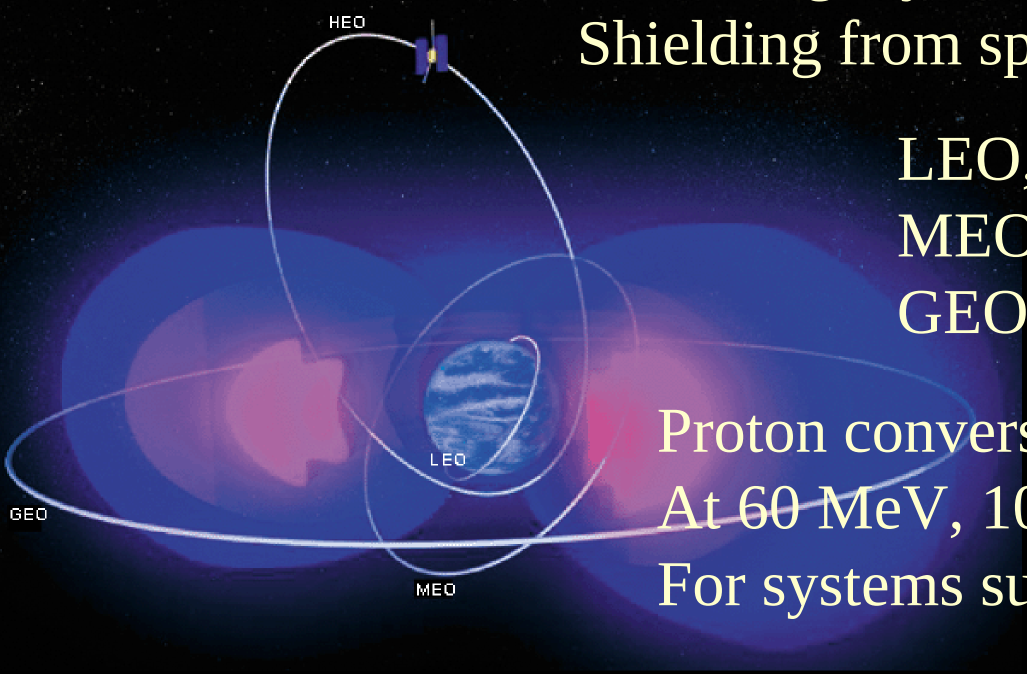
There is no standard, typical and benign –25 to +85 C.
Telcordia is –45°C to +80°C.

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 cycles determination.

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:

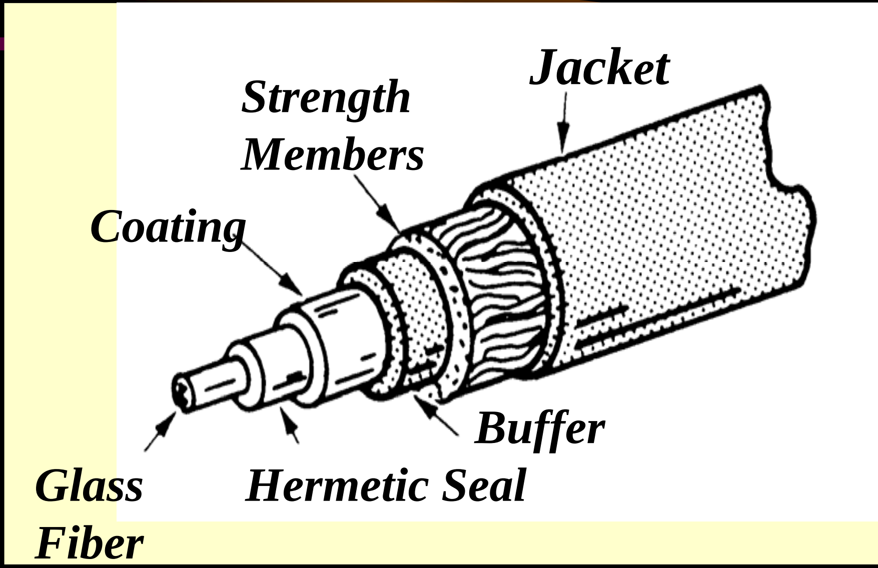
- GLAS, 100 Krads, 5 yr, .04 rads/min
- MLA, 30 Krads, 8 yr, .011 rads/min (five year ave)
- EO-1, 15Krads, 10 yr, .04 rads/min

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.

Lessons Learned

Failure Analysis: Optical Fiber Cable 1999-2000

Bad Combination



Fiber Optic Cable "Rocket Engine" Defects

- Hermetic coating holes,
- Polyimide coating holds water
- Fluorine generated during extrusion of buffer
- Hollow tube construction
  - water and fluorine interaction results in HF acid
- HF etches pits into fiber getting through holes in coating
- Etch pits deep into the core caused losses and cracks

Lessons Learned - Terminations

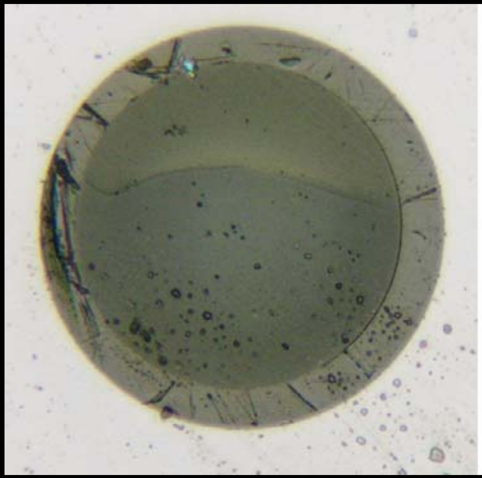
Epoxy curing schedules for space flight applications

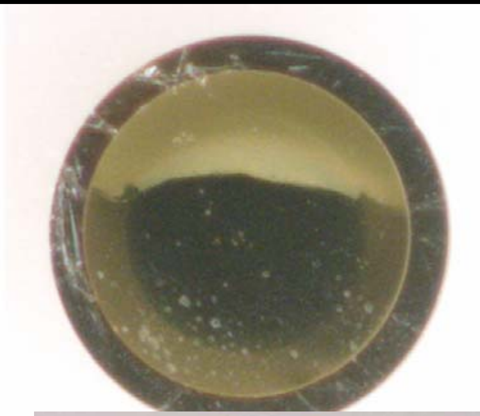
high cure temperatures for terminations =
failures at lower temperature operation

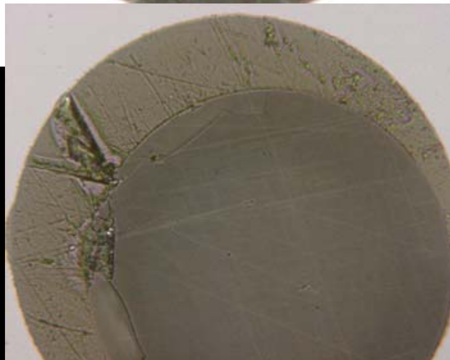
Germanium doped graded-index multimode is very sensitive
Constrained CTE = micro-crack propagation

Germanium doped graded index

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







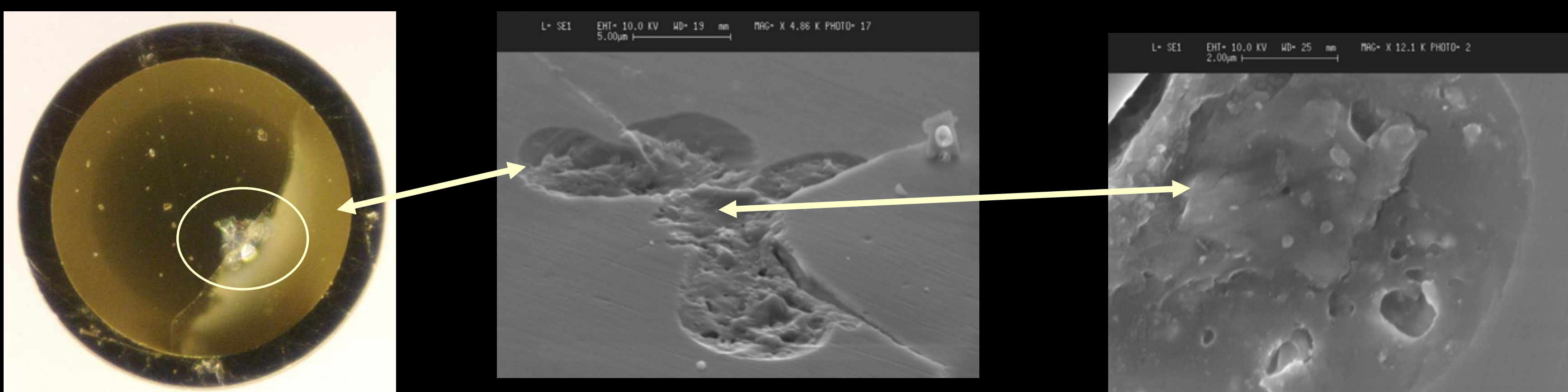
Lessons Learned -Terminations

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

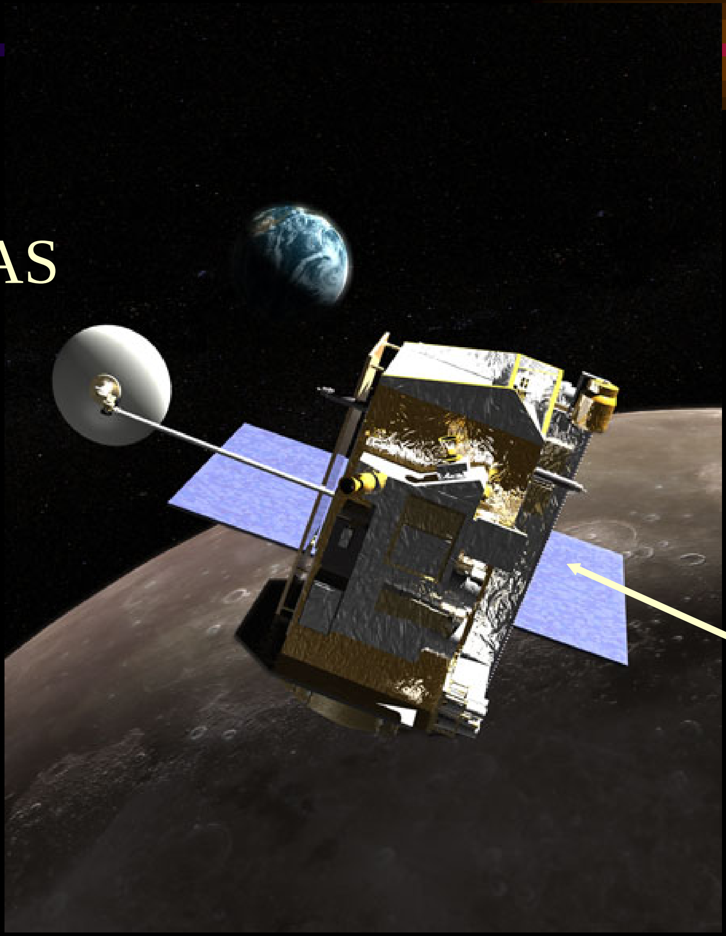


SEM images of contamination – Corrosion on fiber end face

Lunar Recon Orbiter : Laser Ranging and Altimetry

HGAS

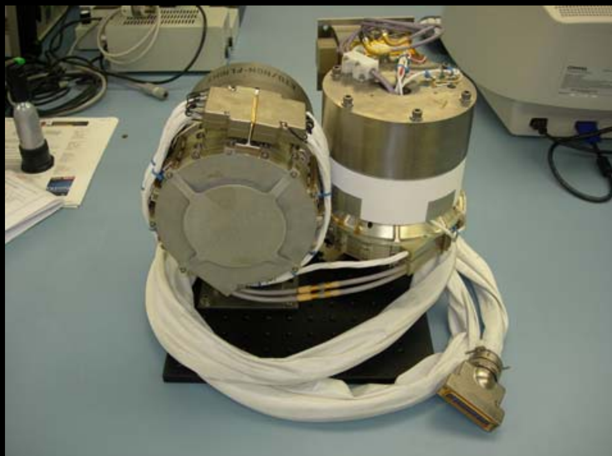
Receiver Telescope mounted on HGA and a fiber array to route signal from HGA to LOLA



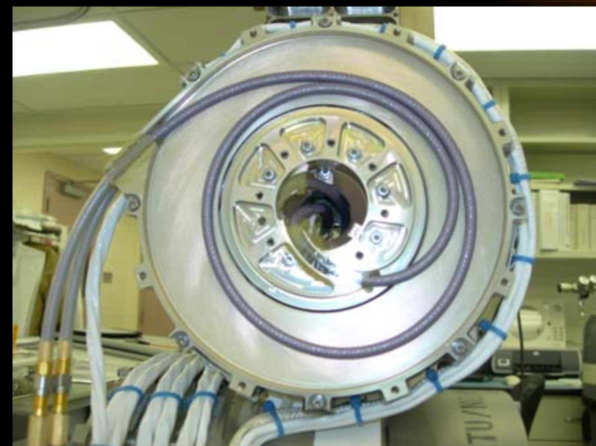
Lunar Orbiter Laser Altimeter LOLA

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

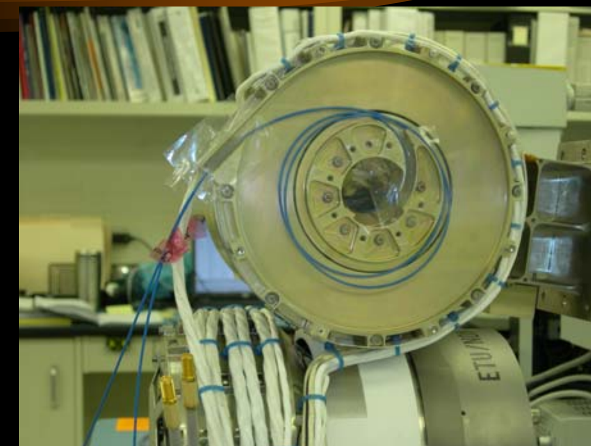
LRO Ranging and Altimetry Test



Gimbals



Window inside gimbal; RF cable wrap



Window inside gimbal; Flexlite MLA cable wrap inside gimbal

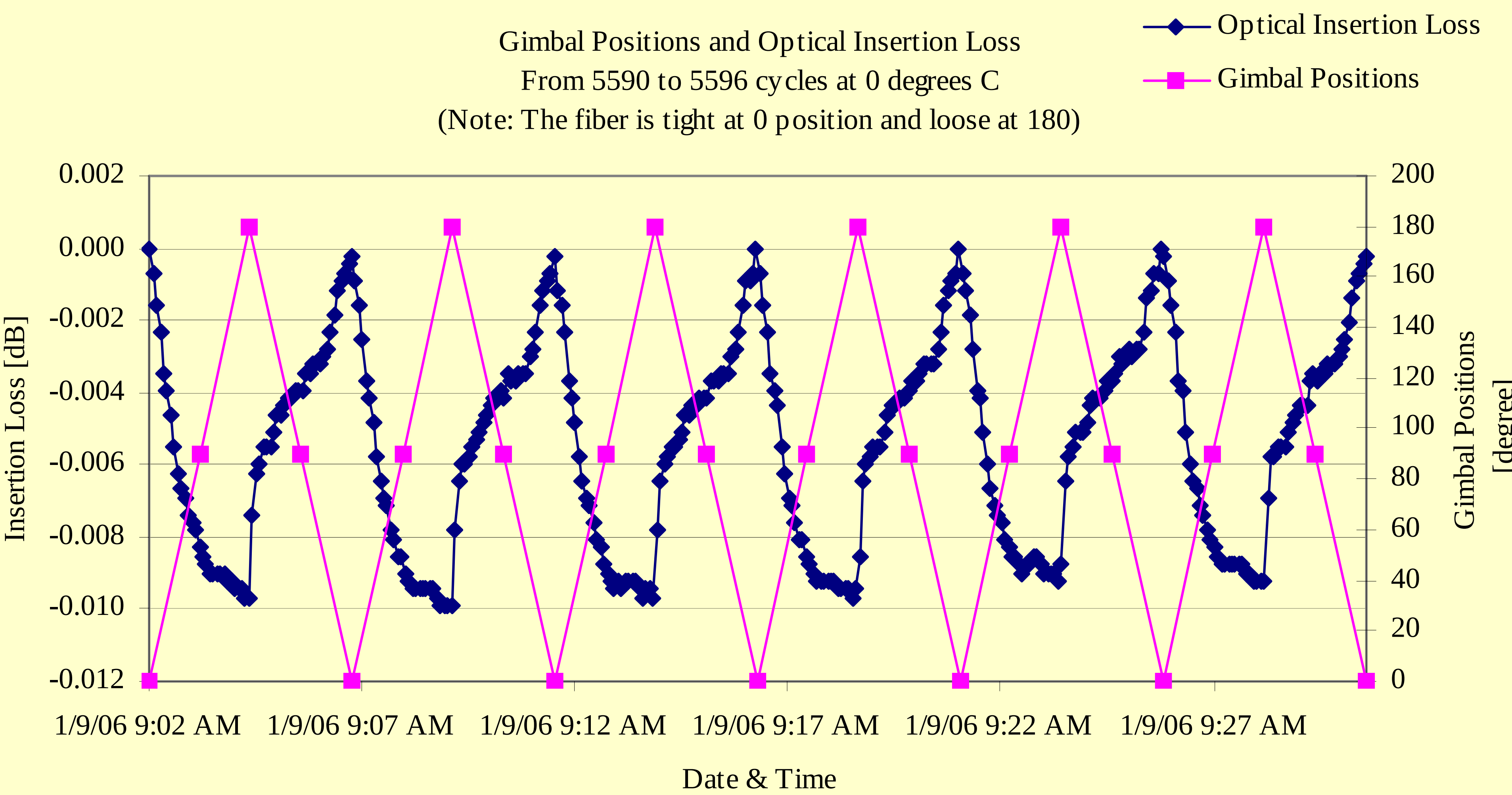
Fiber optic cable (4 m) gimbal test inside of thermal chamber monitored in situ @ 850 nm

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

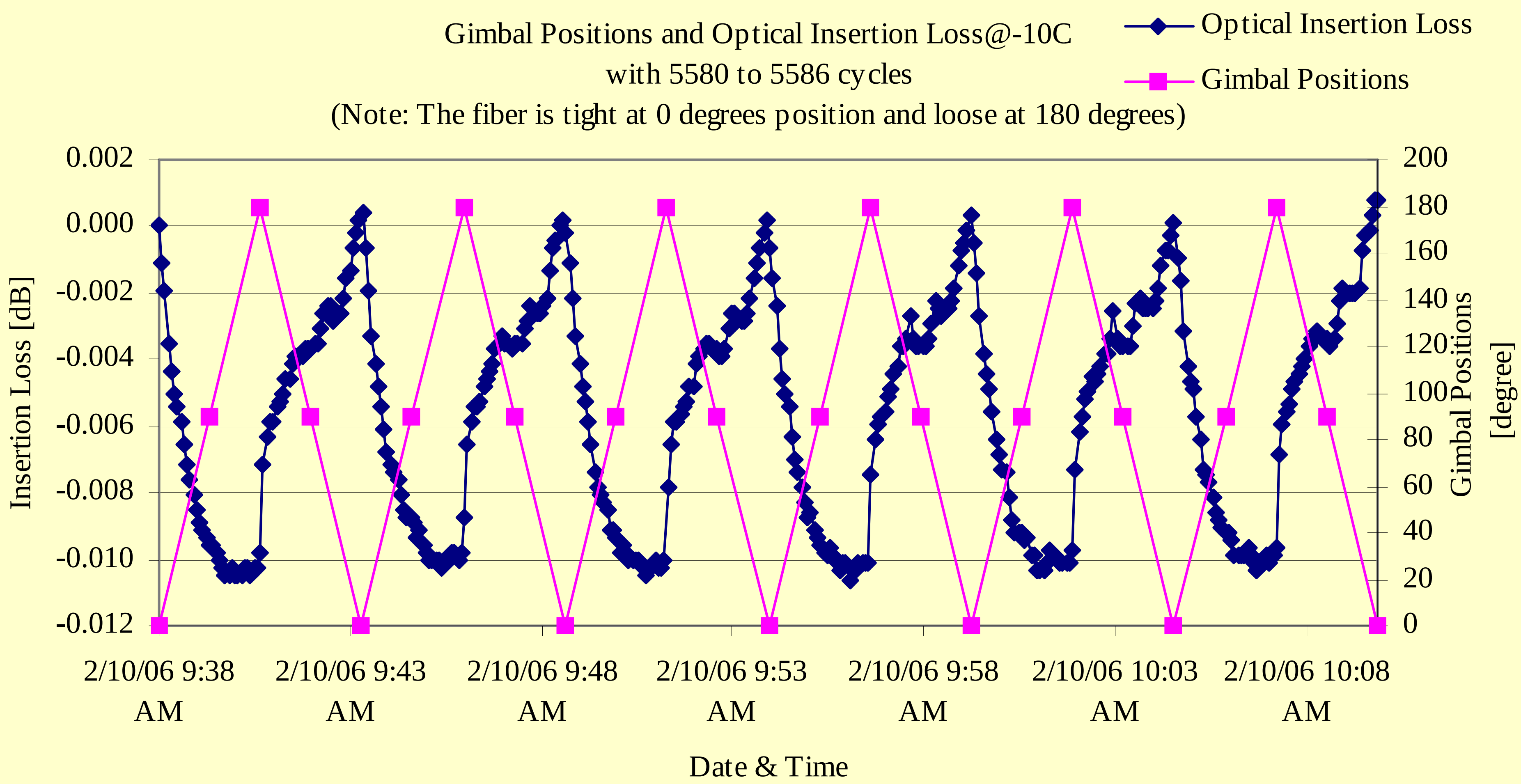
LRO Ranging and Altimetry Gimbal Test

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



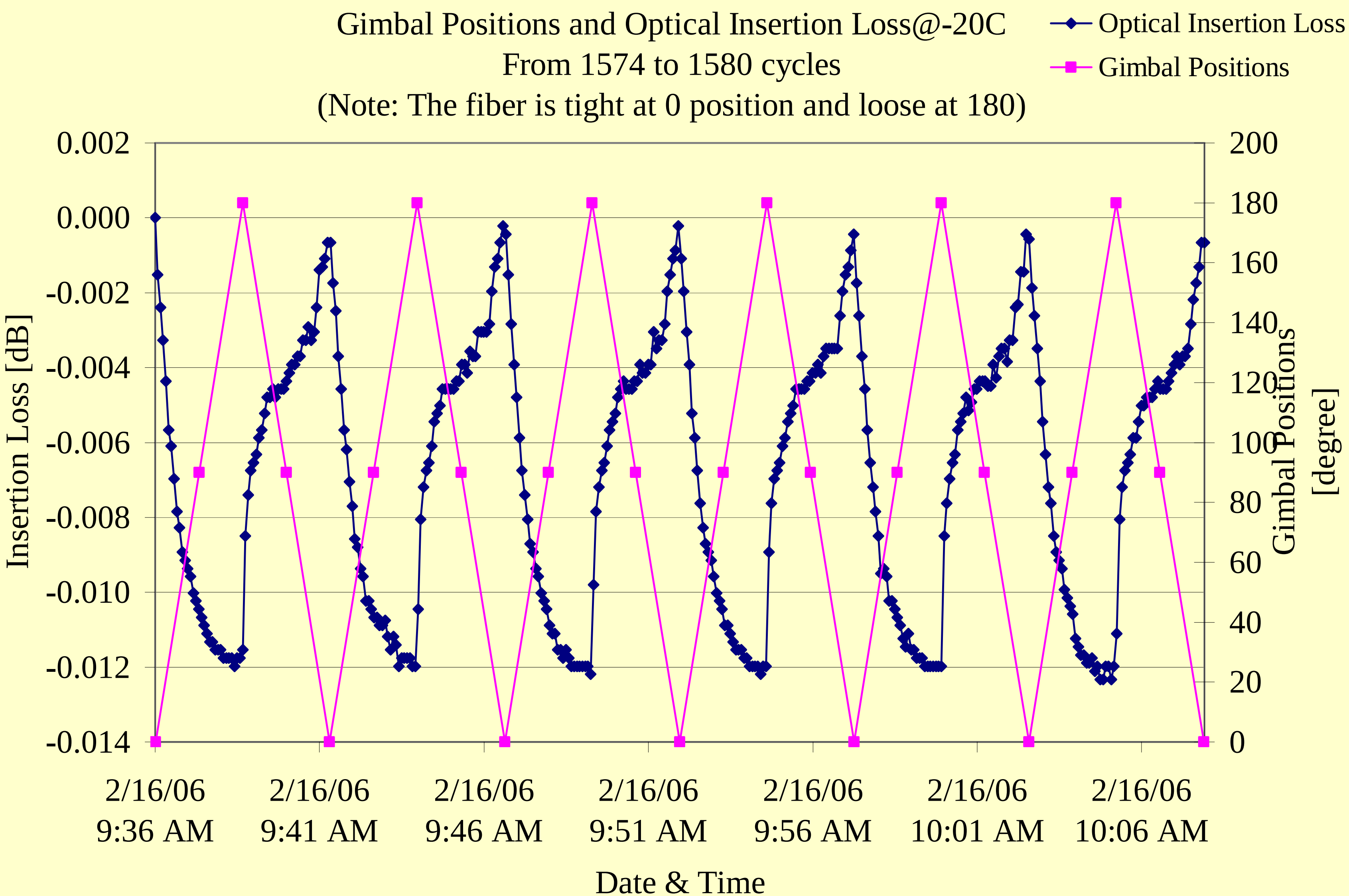
LRO Ranging and Altimetry Test

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



LRO Ranging and Altimetry Test

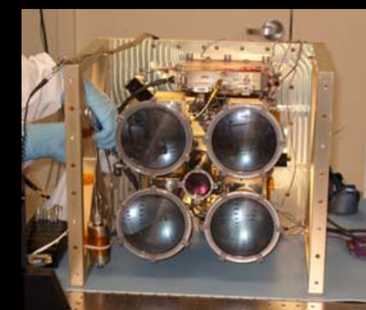
Results of Test 3 at -20°C, Last few gimbal cycles, flex losses < 0.012 dB



Mercury Laser Altimeter and Homer Make News

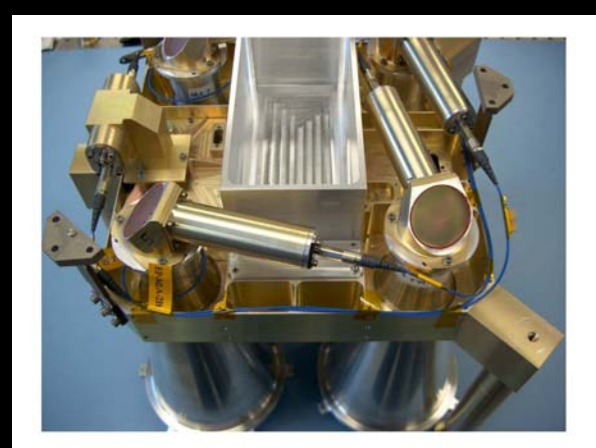
A laser communication link established (MLA to NASA GSFC)
24 million kilometres (15 million miles),

Messenger (Mercury Laser Altimeter) spacecraft and the HOMER Laser (by D. Barry Coyle) at the GSFC ground station.



Transmitted pulses back and forth to each other
No actual information was transmitted but….
Experiment shows the potential for interplanetary laser links

Read the article in
New Scientist Space,
Jeff Hecht, Jan 2006



April 3, 2006

Conclusion

Performance Requirements (System Engineer, Top level Spec)

Environmental Requirements

- Thermal Engineer
- Contamination Engineer
- Radiation Physicist

Physics of Failure--Materials Analysis (crucial!)

- Components Engineer
- Materials Experts

Test Plan tailored to above,

- Define criteria or range of performance allowable.
- Quality by similarity for environmental testing.

Choose Telcordia qualified when you can, plan additional testing.

Thank you for the invitation!

For more information please visit the website:

http://misspiggy.gsfc.nasa.gov/photonics

1) ***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.

2) ***ESA-NASA Workshop-LIDAR Optoelectronics for Space***, June 2006 at ESTEC, Netherlands (Dr. Nikos Karafolas & Melanie Ott)

3) SPIE Optics and Photonics Conference, Aug 2006 USA
   - Atmospheric and Space Optical Systems and Instrumentation
   - Photonics for Space Environments XI

- ***Current Activities in the Photonics Group at NASA GSFC***
- ***Qualification of MTP and Ribbon Cable Assemblies for Space*** (with Sandia National Labs)