Heritage Use and Requirements Validation Testing of the AVIM-Flexlite Assemblies with Polymicro SI Optical Fiber

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Outline

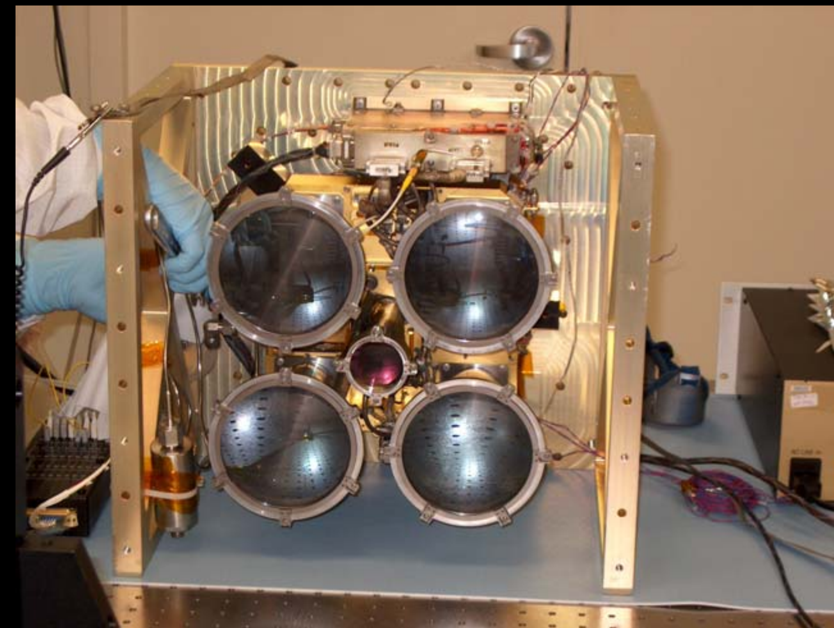
- Introduction
- COTS Requirements Validation Approach.
- Materials Testing
- Vibration Testing
- Thermal Testing
- Radiation Testing

Project Heritage AVIM/Flexlite

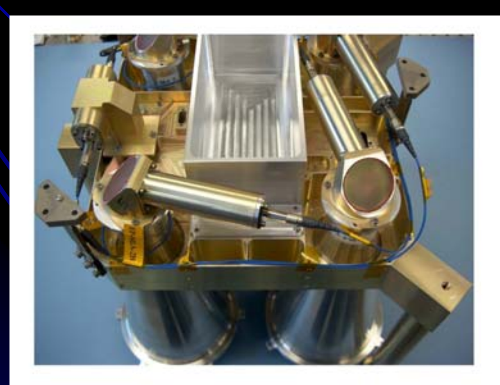
- Mid 1990's Locheed Martin Develops AVIM/Flexlite Combination
- Geoscience Laser Altimeter, 2000
  - Several different types of Fiber
  - Mostly FIA200/220/500 acrylate, Polymicro fiber – Electron Scintillation Testing, broad band.
- Mercury Laser Altimeter, 2003
  - FIA200220500 (flown) – Radiation Data @ 850 nm
  - FIA300330500 (tested) – Radiation Data @ 850 nm
- Lunar Recon Orbiter (Laser Ranging)
  - FVA400440580 (Integration) – Radiation Data @ 532 nm
- Lunar Orbiter Laser Altimeter, 2007
  - FIA200220500 (Integration now) – Radiation Data @ 850 nm

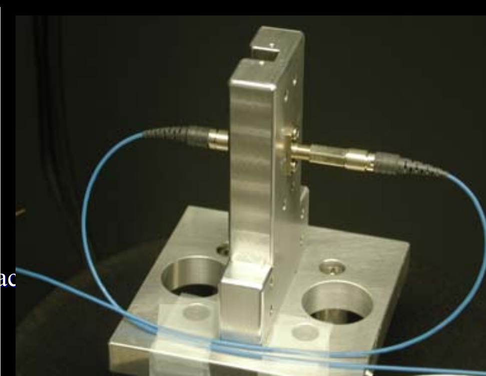
All Fiber 0.22 NA

Mercury Laser Altimeter



- Receiver telescopes focused into the Diamond AVIM standard connector and custom drilled pilz ferrule with FIA200/220/500 Polymicro Fiber in W.L. Gore Flexlite.





COTS Technology Assurance Approach

System Requirements
- Define Critical parameters
- Define acceptable performance parameters for post test
- Define components of modules to be tested
- Define number of samples to test

Parts Selection ↔ **Construction Analysis**
- Knowledge of materials
- Knowledge of construction design, physical analysis
- Destructive physical analysis (FEA for active parts)

Critical Components

Failure Modes Study
- Components
- Modules

Test Methods
- Capture largest amount of failure modes while testing for space experiment

Qualification Test Plan(s)
- Contains necessary testing for mission while monitoring for failure modes

* *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*

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

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.

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

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

Outgas Testing Details on Flexlite with Acrylate Coated Fiber Inside

From M. Ott, ***Technology validation of optical fiber cables for space flight environments***, SPIE Vol. 4216 Nov. 2000.
http://misspiggy.gsfc.nasa.gov/tva/meldoc/cotsfospie2000.pdf

FON1008 passed with acrylate coated fiber

> "Two 1.5 meter samples of the cable with fiber inside were tested at 80°C and at 125°C in a vacuum environment of 10-6 Torr for 24 hours. The cables were open on both ends, unterminated. The results state that the amount of %TML was .24% and .34% respectively. Both results show that acrylate coated fiber can in fact, be used inside of a "non outgassing" cable configuration such as the 1.2 mm FLEX-LITE® series configuration made by W.L. Gore. It was also verified by other data that the %TML did not change with a change in length of the cable. This cable with acrylate fiber inside, passes the requirement of the ASTM-595 outgassing test in a configuration."

Environmental Parameters: Vibration

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

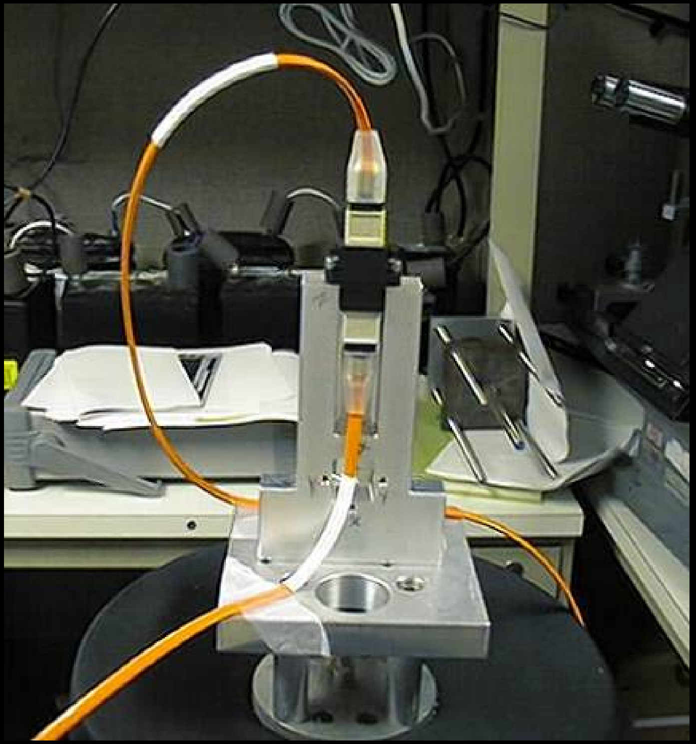
Frequency (Hz)	Protoflight Level
20	0.026 g^2/Hz
20-50	+6 dB/octave
50-800	0.16 g^2/Hz
800-2000	-6 dB/octave
2000	0.026 g^2/Hz
Overall	14.1 grms

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.

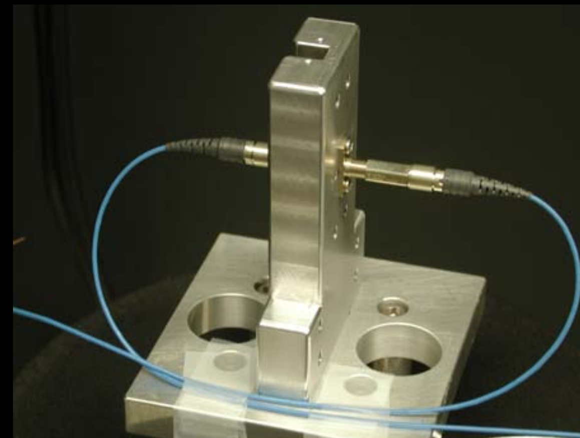
Frequency (Hz)	Protoflight Level
20	0.052 g^2/Hz
20-50	+6 dB/octave
50-800	0.32 g^2/Hz
800-2000	-6 dB/octave
2000	0.052 g^2/Hz
Overall	20.0 grms

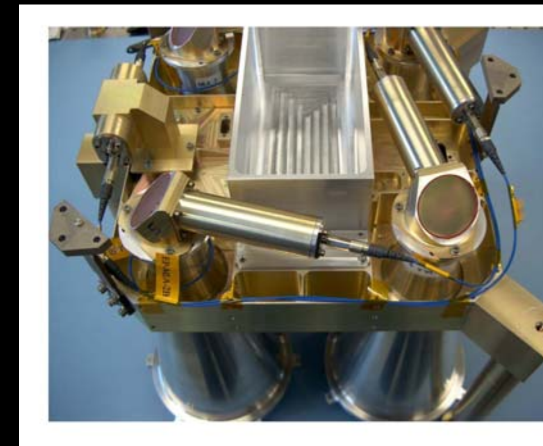


3 minutes per axis, tested in x, y and z

In the absence of other random vibration requirements this is GSFC default from GEVS

MLA Assembly Environmental Validation (MLA)





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

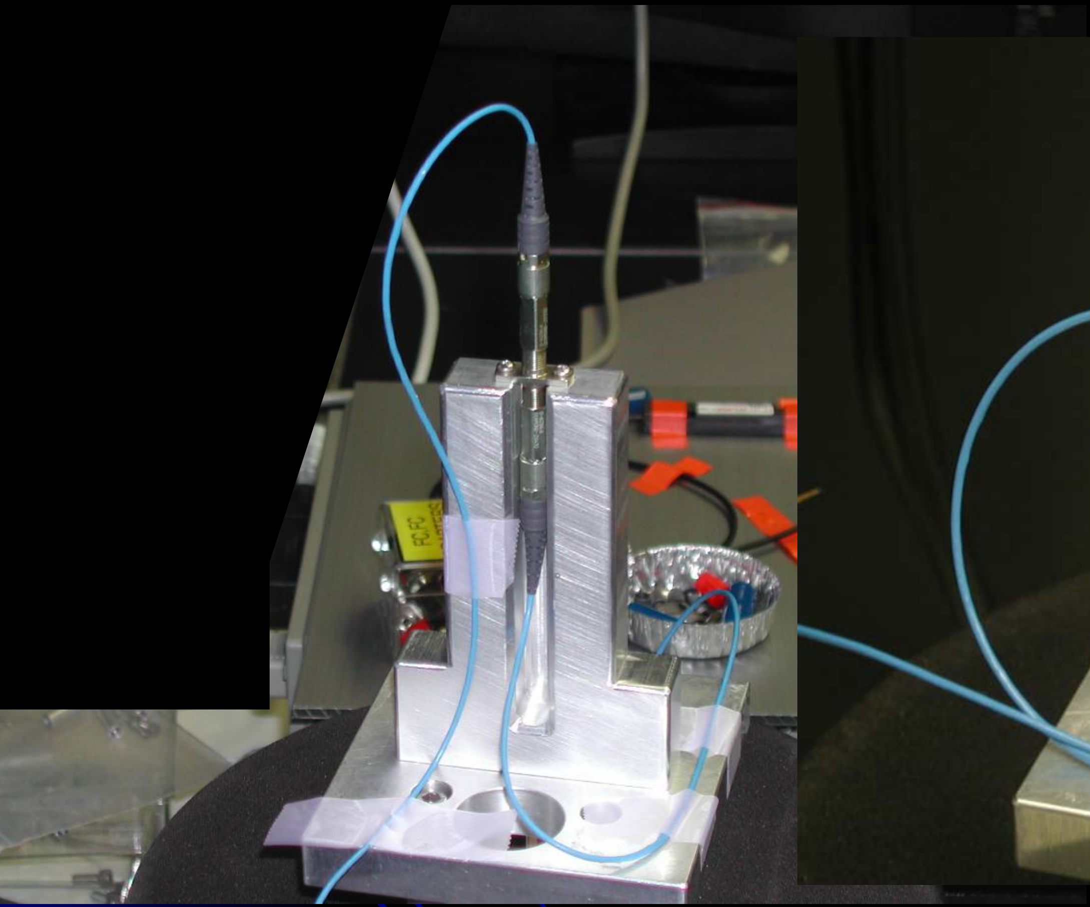
25 minute soak, 2 °C/min ramp rates.

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

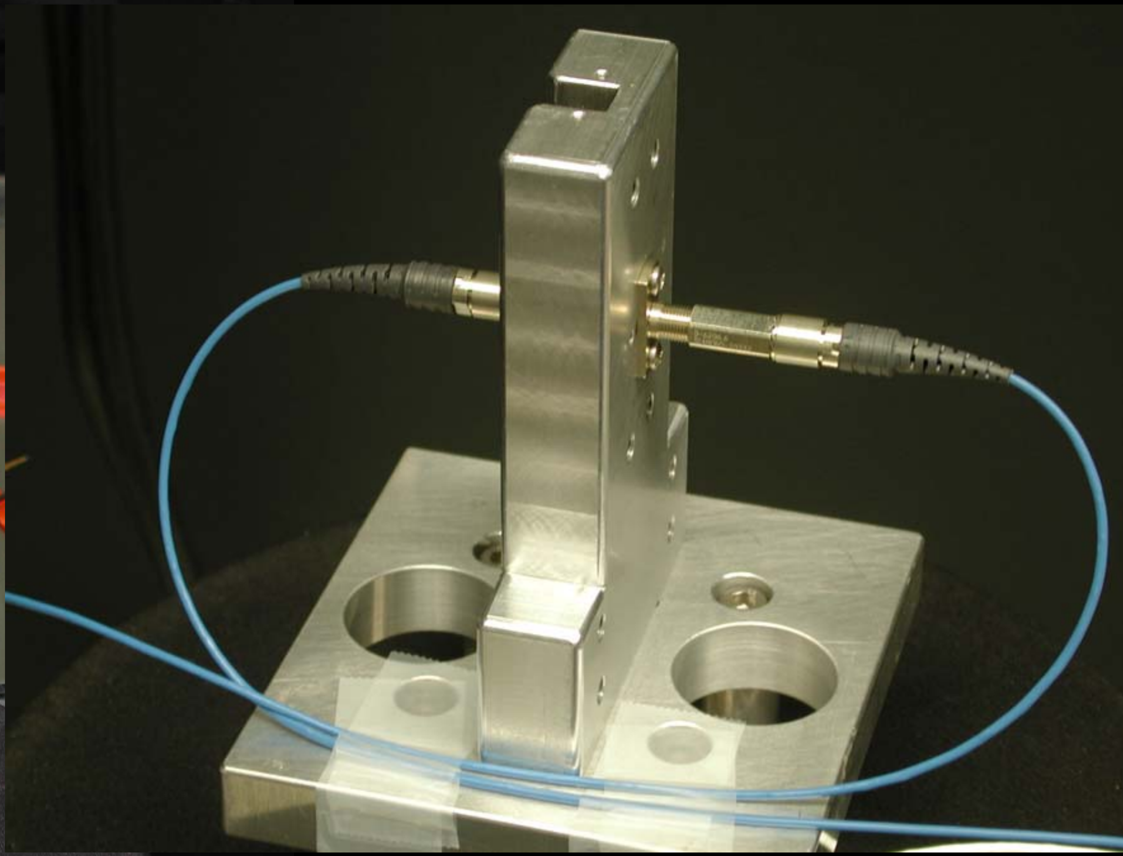
11.2 and 22.7 rads/min to 30 Krads

(Actual dose rate .011 rads/min)

Vibration Testing (MLA)



Z axis orientation



X axis orientation

3 minutes/axis, 14.1 grms total, 3 axis test

Vibration Test Results Summary (MLA)

Assembly Set	Vibration Test Axis	Max Induced Insertion Loss	Final Change in Insertion Loss Post Testing
MP1	X	0.0031 dB	0.0028 dB
MP1	Y	0.0024 dB	0.0012 dB
MP1	Z	0.0015 dB	0.0006 dB
MP2	X	-0.0002 dB*	-0.0027 dB *
MP2	Y	-0.0006 dB*	-0.0012 dB *
MP2	Z	0.0027 dB	0.0004 dB
MP3	X	-0.0005 dB*	-0.0017 dB *
MP3	Y	0.0004 dB	0.00 dB
MP3	Z	0.0003 dB*	-0.002 dB *

*Indicates an increase in power post vibration testing

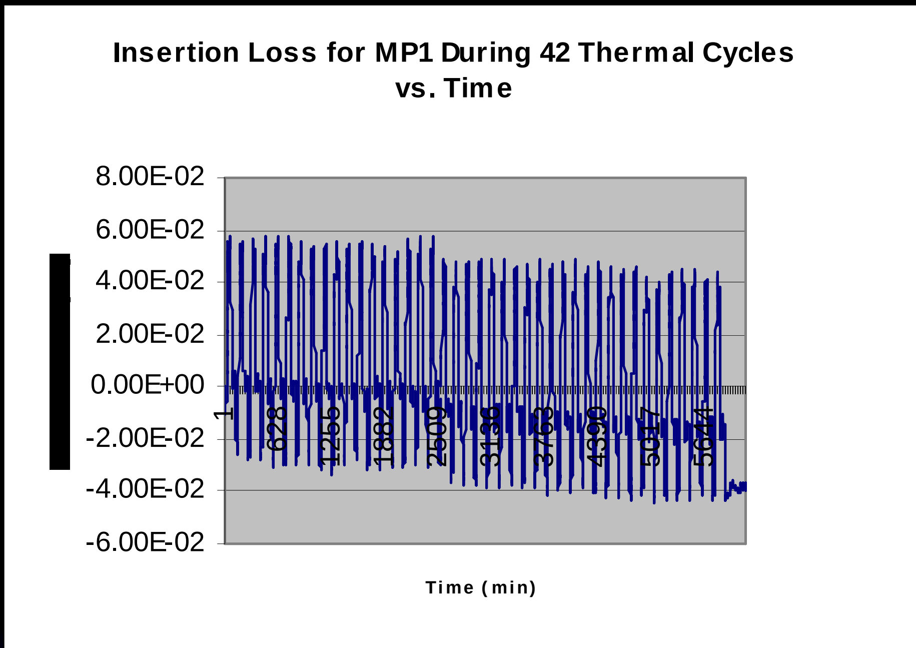
No endface damage was detected during post vibration visual inspection.

Thermal Testing (MLA)

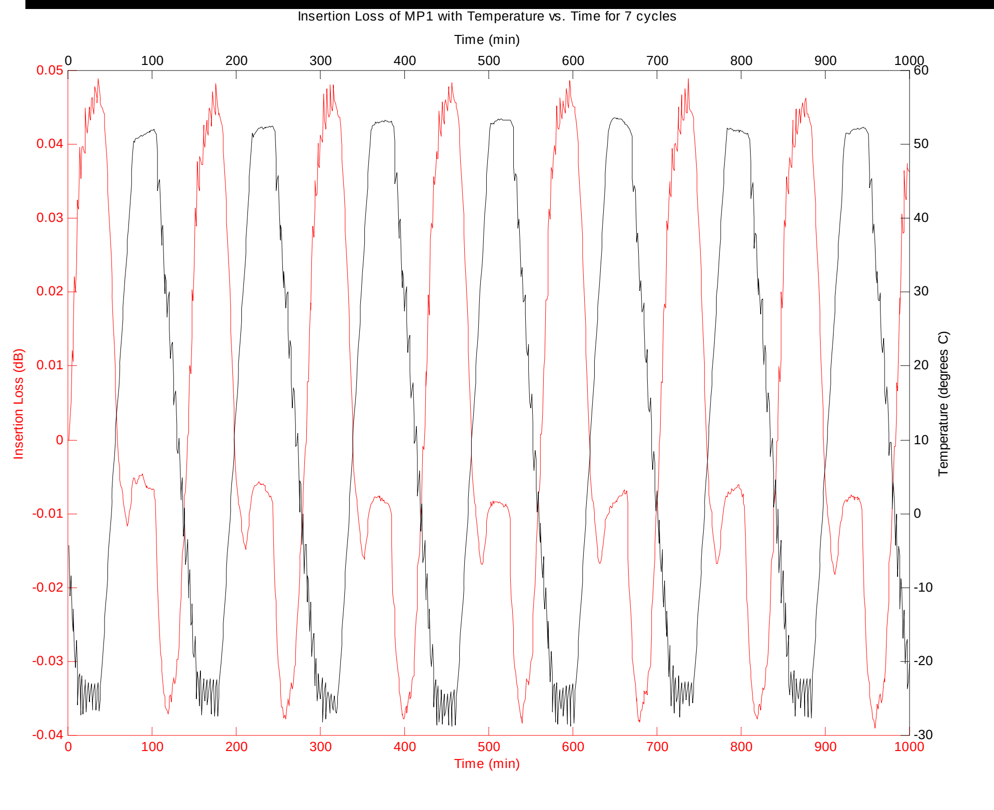
-30°C to +50 °C, 90 cycles, last 42 cycles monitored optically.

Program malfunction caused lack of data collected during the first 48 cycles.

Thermal Testing Results (MLA)

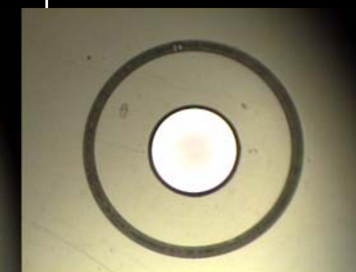
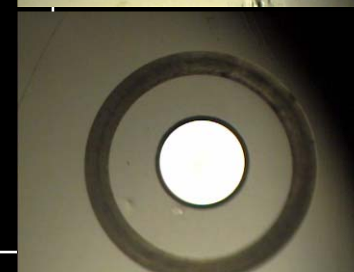


← Example of data collected for all assemblies MP1 during 42 cycles (after initial 48 cycles unmonitored)



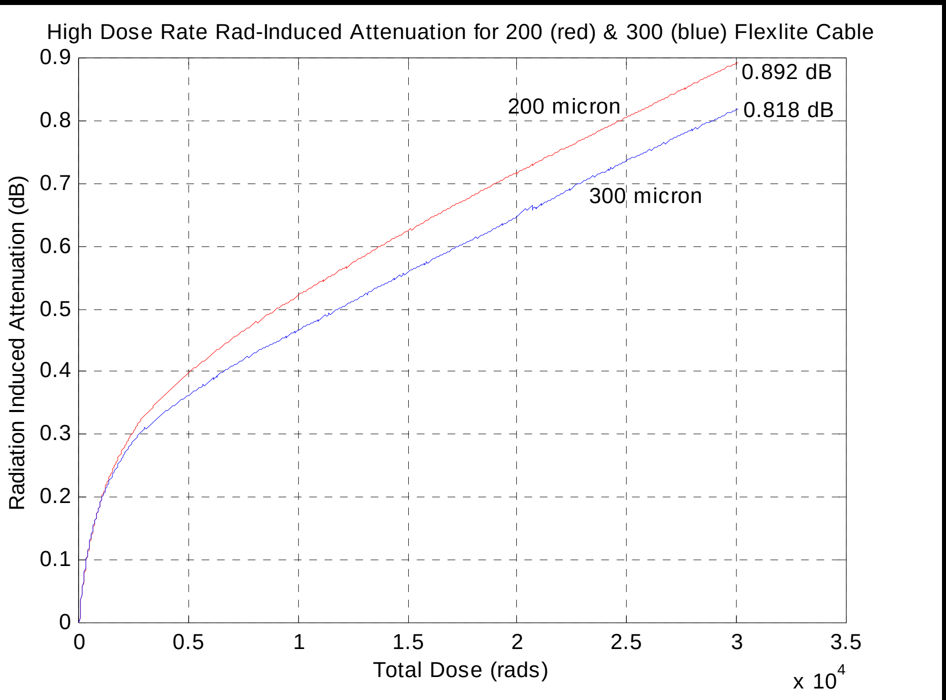
Insertion loss for MP1 → During 68th to 75th cycle (Red) with temperature (Black). Insertion loss increases with decreasing temperature.

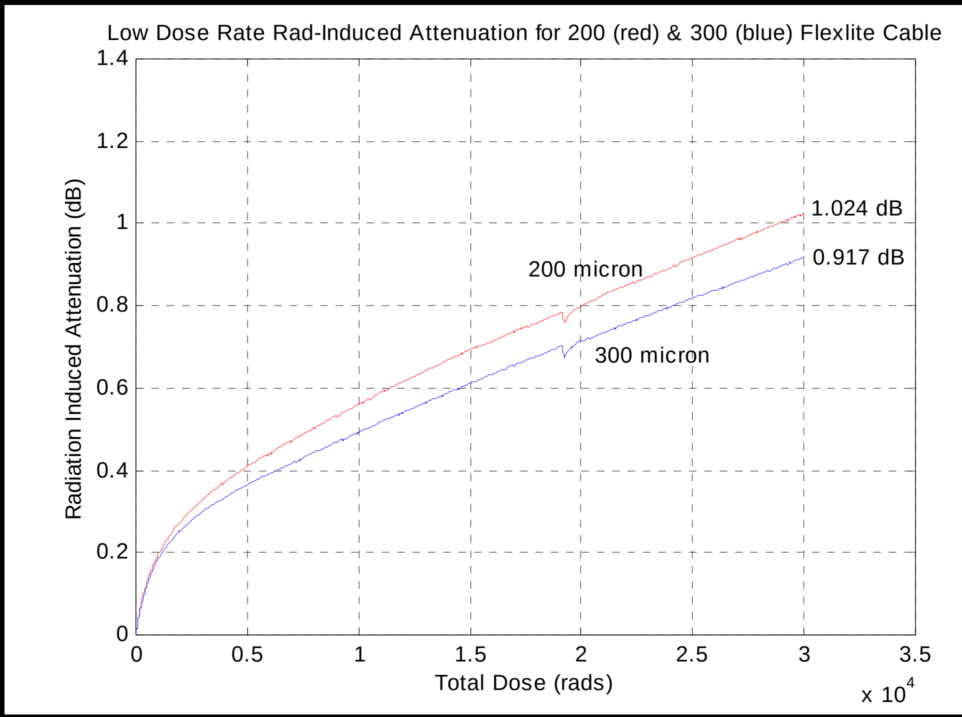
Thermal Testing Results Summary

Assembly Set	Δ insertion loss during testing	Overall Change in loss post testing, 90 cycles	Max insertion loss during testing	Visual Inspection post test side A	Visual Inspection post test side B
MP1	0.09 dB	-0.044 dB power increase	0.058 dB		
MP2	0.07 dB	-0.015 dB power increase	0.037 dB		
MP3	0.04 dB	-0.035 dB power increase	0.024 dB		

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

MLA Assembly Radiation Validation



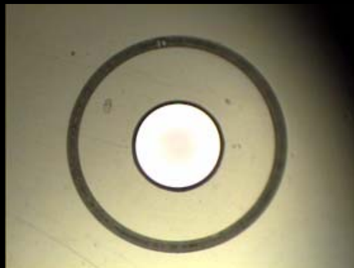


Flexlite Radiation Test, 22.7 rads/min at –18.3°C

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



The 24 Million Km Link with the Mercury Laser Altimeter

Jay Steigelman
Dave Skillman
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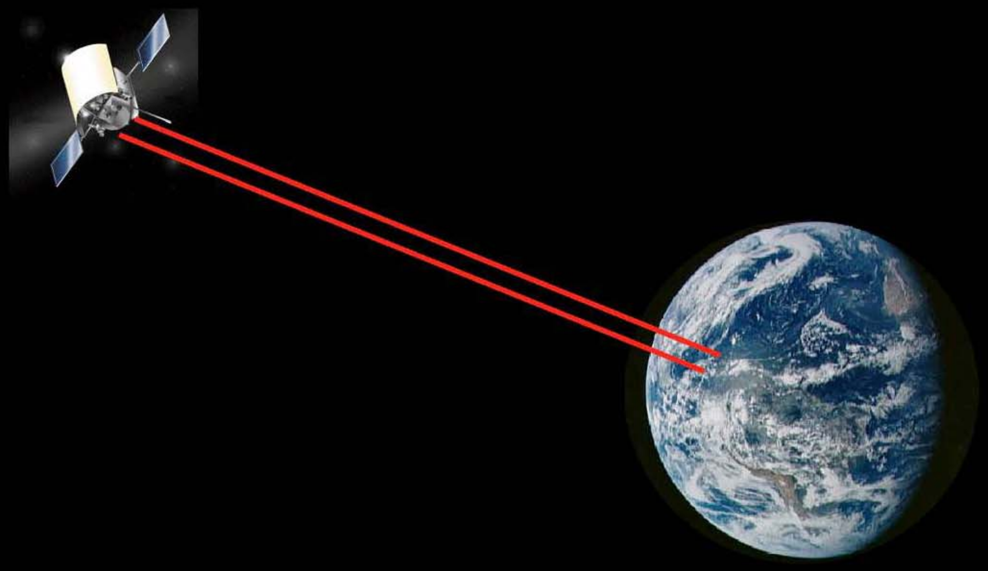

MOLA Science Team Meeting
Bishop's Lodge, Santa Fe, NM
August 24-25, 2005

MESSENGER
Recent Publications

Two-Way Laser Link over Interplanetary Distance

David E. Smith,[1*] Maria T. Zuber,[1,2] Xiaoli Sun,[1] Gregory A. Neumann,[1,2] John F. Cavanaugh,[1] Jan F. McGarry,[1] Thomas W. Zagwodzki[1]

The detection and precise timing of low-energy laser pulses transmitted over interplanetary distances will enable advances in fundamental physics and solar system dynamics (*1*), as well as high-bandwidth deep-space communications (*2*, *3*). The MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) spacecraft (*4*), launched 3 August 2004, is carrying the Mercury Laser Altimeter (MLA) (*5*) as part of its instrument suite on its 6.6-year voyage to Mercury. In an experiment performed before an Earth flyby, the MLA successfully ranged to Earth and received laser pulses from the NASA Goddard Geophysical and Astronomical Observatory (GGAO) (*6*).

The only other deep-space laser ranging demonstration occurred before MLA in 1992, when two ground-based lasers were pointed toward the Galileo spacecraft and the signals were detected at a distance of 6×10^6 km as streaks of light by the spacecraft's camera (*7*). In contrast, the MLA Earth-ranging experiment operated like an asynchronous transponder (*8*), in which space-based and Earth-based laser terminals independently fired timed pulses at each other, with the transmitted and received pulse times linked by means of a stable spacecraft clock. The times of the paired observations were used to solve for a common range and clock offset (*6*).

The MESSENGER spacecraft clock is an ovenized quartz oscillator (*4*) that measures mission elapsed time (MET) and is periodically synchronized to coordinated universal time (UTC) by the terrestrial reference system terrestrial dynamic time. Over the test period 26 to 31 May 2005, the spacecraft clock, to which the MLA is periodically calibrated, was stable to approximately one part per billion (ppb).

In three observing opportunities, the MLA laser was fired for 5-hour periods while the spacecraft scanned Earth at a rate of 16 μrad s^{-1} along lines spaced 32 μrad apart, for a total scan area of 3.2 by 3.2 mrad. Event timers logged pulse transmission and arrival times at GGAO, referenced to UTC within 100 ns absolute time. A digital oscilloscope at a frequency of 1 GHz also recorded the received pulse shapes. Sixteen consecutive pulses were recorded at 19:47:24 UTC on 27 and 24 May; more were recorded at 19:42:02 UTC on 31 May.

Simultaneously, a laser at GGAO was beamed upward toward MLA. The uplink pulses, along with noise triggers from the sunlit Earth, were received within a 15-ms range window during each 125-ms shot interval. Inspection of the stored instrument data revealed 90 pulses over a 30-min time frame, 17 on multiple channels, whose timing matched the GGAO fire times.

The interpretation of these events as downlink and uplink ranges required a joint solution (*6*) for spacecraft clock and state parameters (Fig. 1). The solution yielded a clock offset and drift rate at the origin time and the range as a function of time at the spacecraft (Table 1) (*9*). Downlink observations were fit with a root mean square residual of 0.39 ns, whereas uplink observations suffered from marginal signal link and were fit with an rms residual of 2.9 ns. Formal standard deviations indicate that the range was determined with an accuracy of ±20 cm. Our range agrees with that derived from the reconstructed ephemeris from X-band Doppler tracking (7.2 GHz uplink; 8.4 GHz downlink) to within 52 m. This experiment has demonstrated subnanosecond laser pulse timing and accomplished a two-way laser link at interplanetary distance. In addition, it established a distance record for laser transmission and detection.

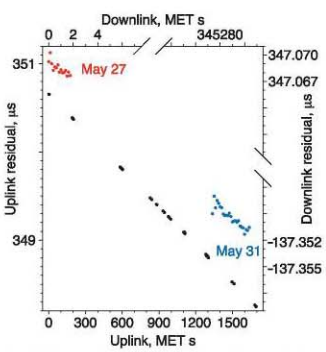

Fig. 1. Pulse-received times at MLA and GGAO. The graph shows that ground laser pulses (black symbols) were received by MLA ~0.35 ms earlier than predicted. Similarly, the ground-receive time of MLA pulses was ~0.34 ms earlier on 27 May (red symbols) but ~0.14 ms later on 31 May (blue symbols).

Table 1. Solution parameters.

Parameter	Laser link solution	Spacecraft ephemeris	Difference
Range (m)	23,964,675,433.9 ± 0.2	23,964,675,381.3	52.6
Range rate (m s^{-1})	4,154.663 ± 0.144	4,154.601	0.062
Acceleration (mm s^{-2})	−0.0102 ± 0.0004	−0.0087	−0.0015
Time (s)	71,163.729670967 ± 6.6×10^{-10}	71,163.730019659	0.000348692
Clock drift rate (ppb)	1.00000001559 ± 4.8×10^{-10}	1.00000001564	-3.2×10^{-10}

References and Notes

1. D. E. Smith, M. T. Zuber, J. J. Degnan, J. B. Abshire, paper presented at Marcel Grossman 8, Jerusalem, 1997.
2. J. Bland-Hawthorn, A. Harwit, M. Harwit, *Science* **523**, 293 (2002).
3. B. L. Edwards *et al.*, paper presented at *AIAA* (2003).
4. A. G. Santo *et al.*, *Planet. Space Sci.* **49**, 1481 (2001).
5. J. F. Cavanaugh *et al.*, in preparation.
6. Materials and methods are available as supporting material on *Science* Online.
7. K. E. Wilson, J. R. Lesh, T.-Y. Yan, *Proc. SPIE* **1866**, 138 (1993).
8. J. J. Degnan, *J. Geodynam.* **34**, 551 (2002).
9. The range is not a true geometric time of flight because both terminals are accelerating, but the round-trip time is adequately constrained in this fashion.
10. We gratefully acknowledge the efforts of the MESSENGER spacecraft team, the MLA instrument team, and the staff of NASA's GGAO. The MESSENGER Project is supported by NASA's Discovery Program.

Supporting Online Material
www.sciencemag.org/cgi/content/full/311/5757/53/DC1
Materials and Methods
Table S1
References and Notes

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10.1126/science.1120091

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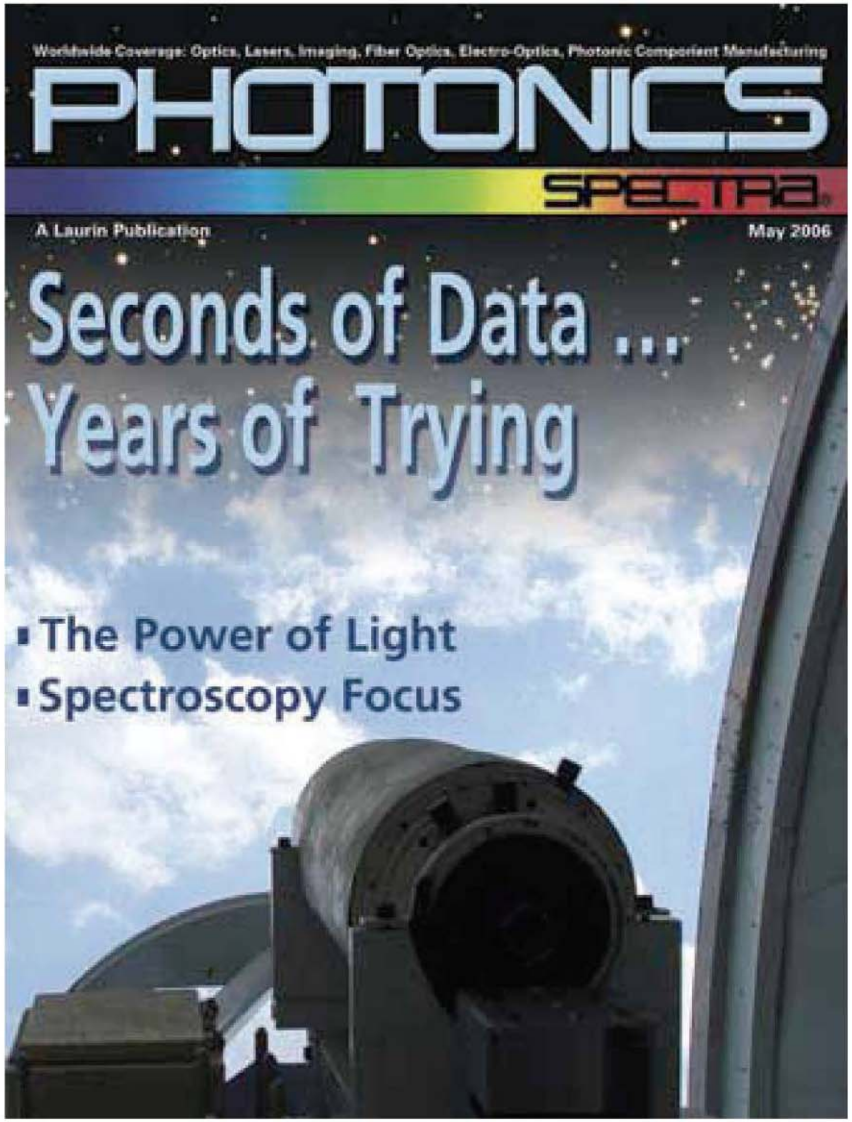
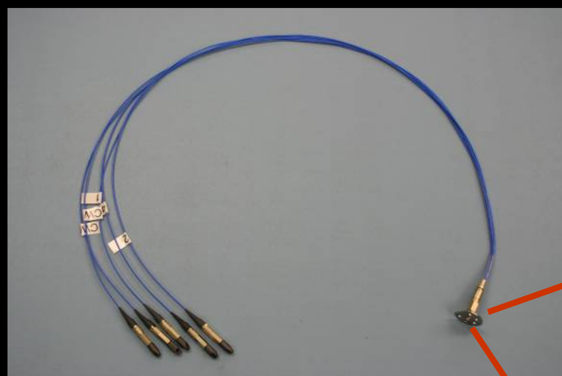
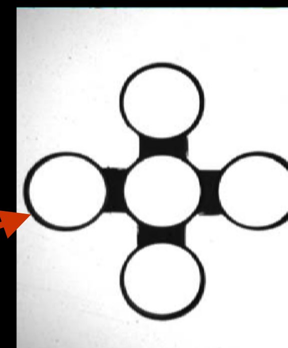
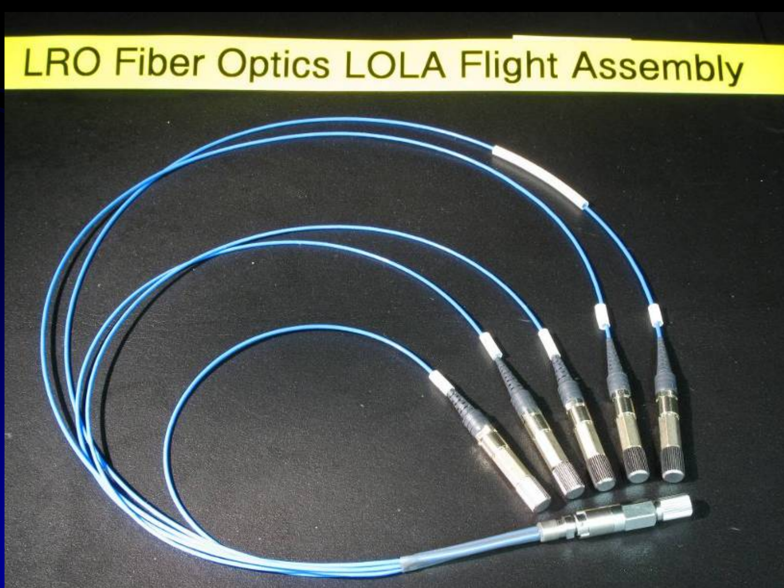


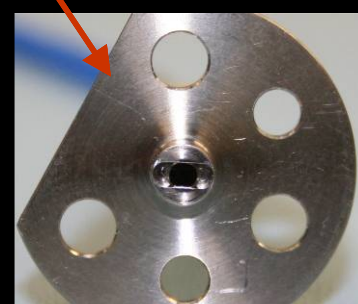
LOLA Five-Fiber Array Assembly Configuration





AVIM PM Connector

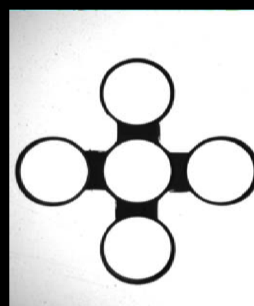


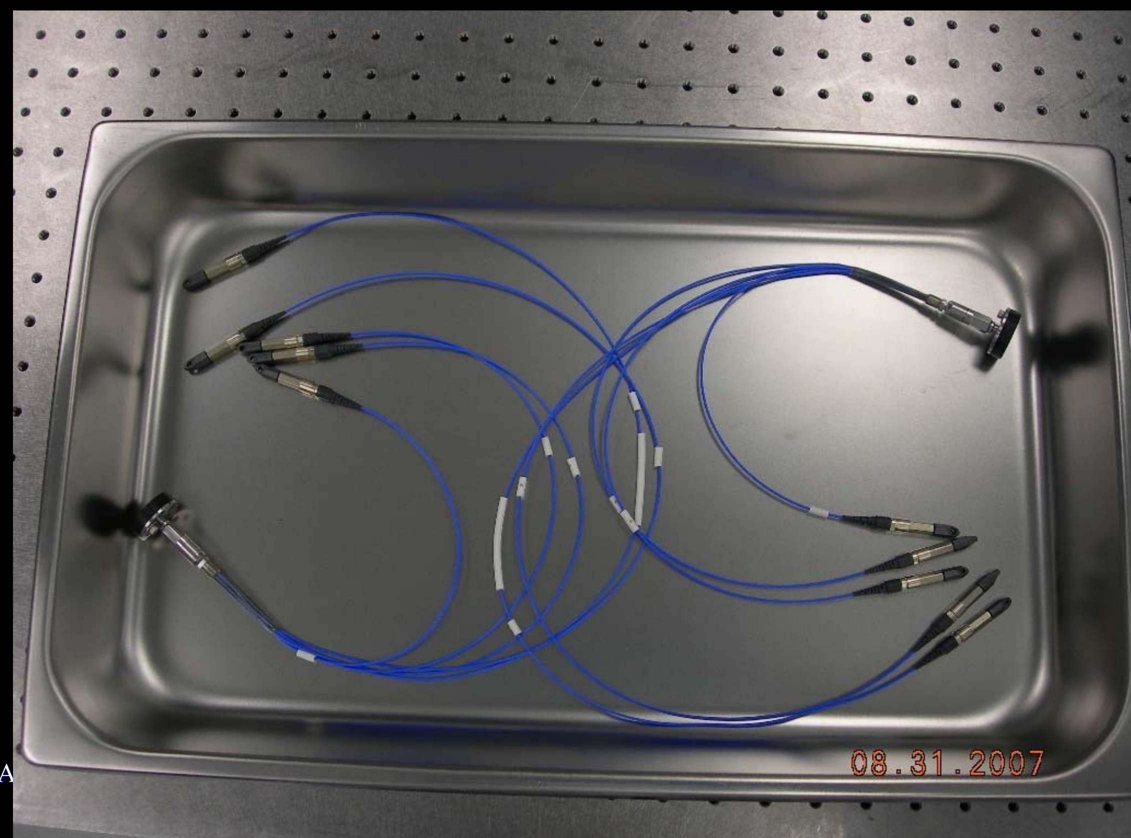


LOLA Specific Adapter desig
in-house by GSFC

Final FOB LOLA Array Assembly Flight Configuration

Custom LOLA Adapter with Ferrule Engagement Flats, Code 544
Standard AVIM (MLA & GLAS heritage) Fan Out Flight Connectors
Custom AVIM PM Optical Fiber Connector, Diamond Switzerland
Custom SS 303 Ferrule Blanks, Diamond Switzerland
Custom Ferrule Drilling, Code 544/541
Flexlite cable FEP/EPTFE Jacket and buffer, W.L. Gore
Polymicro Technologies FI200220500 acrylate, step index .22 NA Optical Fiber
Epotek 353 ND fiber epoxy, Scotchweld 2216 epoxy for strength, Kynar heat shrink tubing





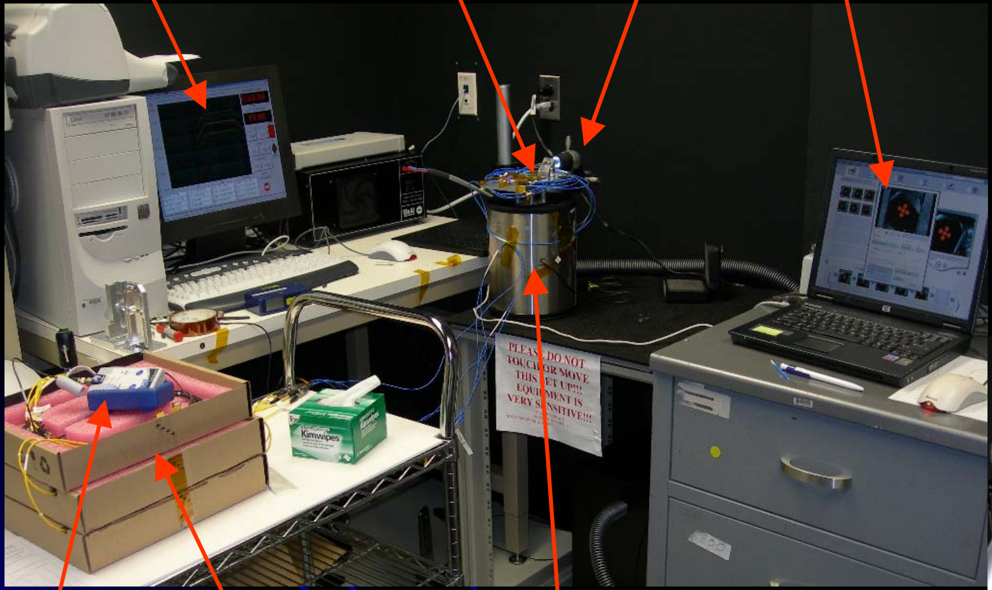
Qualification Test Plan

All testing conducted: recorded before and after optical performance data as well as in-situ optical data.

- Random Vibration Testing
  - Verify survival and operational ability during launch using typical launch parameters for components reliability.
  - 3 axis test, 3 minutes per axis, 20.0 grms total.
- Thermal Cycling Testing
  - Verify the assemblies would survive and maintain an acceptable amount of transmission when exposed to the long-term thermal stresses
  - -30°C to +60°C, 2°C/min ramp rate, 30 minute soak at each extreme, 60 thermal cycles total.
- Gamma Radiation Testing
  - Two dose rates used to provide a model for extrapolation to other dose rates.
  - Two temperatures used to provide a model for extrapolation to different temperatures.

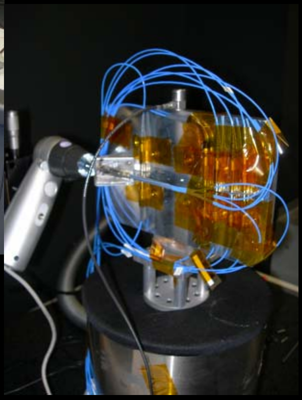
Random Vibration Testing Setup (LOLA)

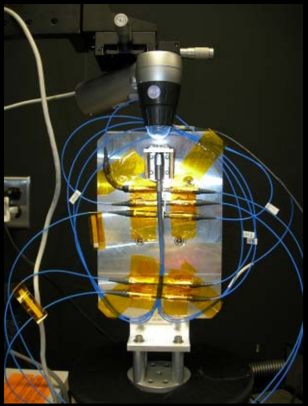
- 3 minutes/axis insitu, 20.0 grms total

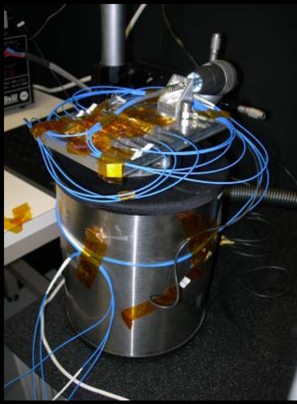


Vibration Profile

Frequency (Hz)	ASD Levels
20	.052 g^2/Hz
20-50	+6 dB/Octave
50-800	.32 g^2/Hz
800-2000	-6 dB/Octave
2000	.052 g^2/Hz
Overall	**20.0 grms**







Vibration Induced Losses (LOLA)

LOLA-EM-008:

	Fiber #1	Fiber #2	Fiber #3	Fiber #4	Fiber #5
Pre-Vibe	0.51	0.33	0.15	0.59	0.46
Post-Vibe	0.43	0.32	0.19	0.42	0.37
Δ (IL)	-0.08	-0.01	0.04	-0.17	-0.09

LOLA-EM-010:

	Fiber #1	Fiber #2	Fiber #3	Fiber #4	Fiber #5
Pre-Vibe	0.39	0.35	0.28	0.32	0.29
Post-Vibe	0.39	0.34	0.31	0.28	0.26
Δ (IL)	0	-0.01	0.03	-0.04	-0.03

LOLA-EM-011:

	Fiber #1	Fiber #2	Fiber #3	Fiber #4	Fiber #5
Pre-Vibe	0.41	0.36	0.42	0.45	0.45
Post-Vibe	0.34	0.35	0.34	0.42	0.38
Δ (IL)	-0.07	-0.01	-0.08	-0.03	-0.07

Conclusion: No significant changes

Radiation Comparison

1) Is Polymicro fiber construction within the same fiber construction (i.e. FV and FI constructions) is consistent over a several year period?

2) Does core/clad diameter variations show significant difference within the same style of fiber construction?

MLA 2003 Data vs. LOLA 2007
1) Does Polymicro Fiber Perform the Same Over Time

Project	Year	Dose Rate	Total Dose	Temperature	Attenuation
MLA Data SPIE 5104	2003	22.7 Rads/min	30 Krads	-18.3 C	0.089 dB/m
LOLA Model SPIE 6713	2007	22.7 Rads/min	30 Krads	-18.3 C	0.070 dB/m

Based on FIA200/220/500 in Flexlite @ 850 nm

Using the same parameters from the MLA Data published in 2003 in the LOLA Model generated from test data published in 2007
Very little difference in performance for the Polymicro FIA200/220/500 .22 NA Optical Fiber in Flexlite. < 0.02 dB

MLA Radiation Data, 2) Does Core Size Matter?

There is only about 0.0074 dB/m difference between the Polymicro 200/220um fiber and the Polymicro 300/330um fiber. Size makes very little difference since 200 more susceptible as well.

Table 5: Summary of Radiation Induced Attenuation on MLA Assemblies

Part Number	Fiber Type (microns)	Dose Rate	Atten @ 30 krads	Ave.Temp during Test	Expected Atten 26.1 inches @ 30 krads
FON1173	200	11.2 rads/min	1.024 dB	-24.1 °C	.068 dB
FON1174	300	11.2 rads/min	0.917 dB	-24.1 °C	.061 dB
FON1173	200	22.7 rads/min	0.892 dB	-18.3 °C	.059 dB
FON1174	300	22.7 rads/min	0.818 dB	-18.3 °C	.054 dB

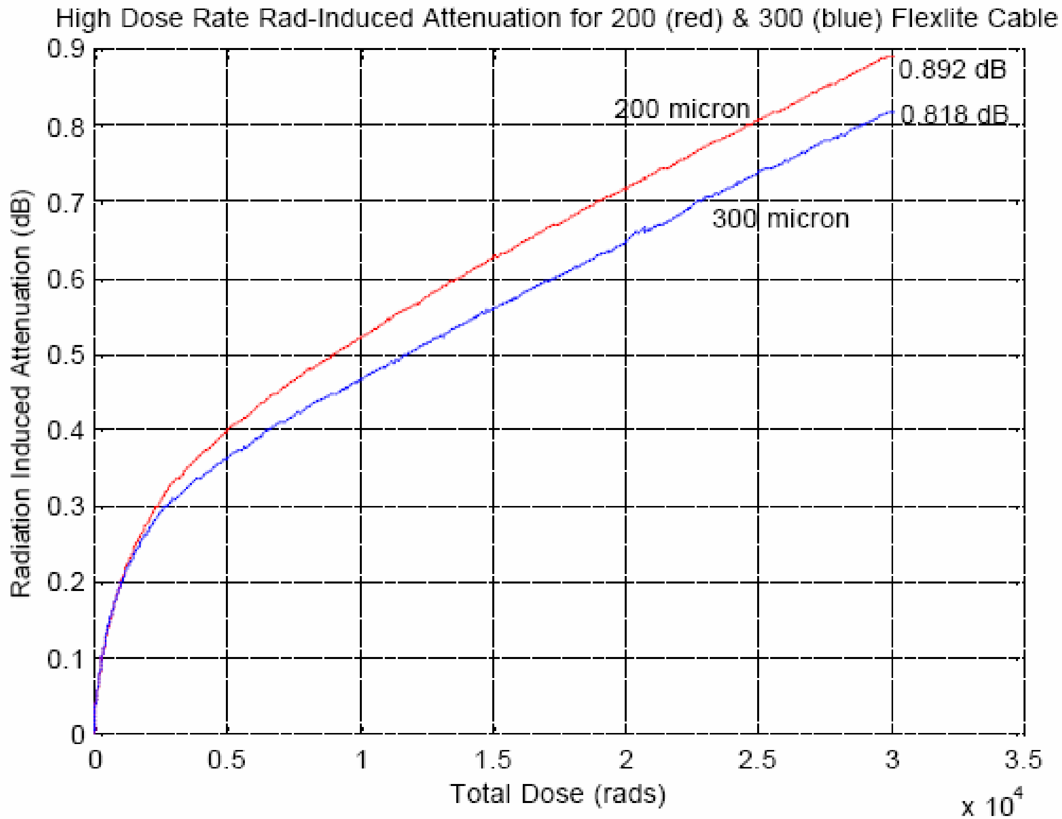


Figure 10: High Dose Rate Test Results to 30 krads of the 200 and 300 micron Optical Fiber FLEX-LITE™ Cable (10 meters).