Optical Fiber Array Assemblies for Space Flight from the NASA Electronics Parts and Packaging Program

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Outline

• Introductions
• LRO (LOLA & LR) Introduction & Requirements
• LRO Solutions
• Design to Integration
  – Lessons Learned
  – Integration
• Conclusions
Mentorship Mapping

Arnold Sommerfeld
Russia, 1868 - 1951
German Physicist
Quantum Theory

Karl F. Herzfeld
Vienna, 1892 – 1978
John’s Hopkins University Professor, 1926
Catholic University Professor, 1936

Henning Leidecker, USA,
Catholic University Professor, 1967
NASA Goddard Space Flight Center, 1985
NASA GSFC Chief Parts Engineer, Currently

Students/Nobel Laureates
1) Werner Karl Heisenberg, 1901-1976,
   Quantum Mechanics
2) Wolfgang Ernst Pauli, 1900 – 1958,
   Theoretical Physics, uncertainty principal
3) Peter Joseph William Debye, 1884 - 1966
   Physics, Physical Chemistry
4) Hans Albrecht Bethe 1906 – 2005, Physics
5) Herbert Kroemer, 1928 -
6) Linus Carl Pauling, 1901 - 1994

Melanie N. Ott
Melanie N. Ott, Group Leader, 1994-2008
Applied Engineering Technologies Directorate, Electrical Engineering Division

Rob Switzer, Frank LaRocca, W. Joe Thomes, Melanie Ott, Richard Chuska
# A Decade of Service from the Photonics Group for Photonics & Optical Fiber Components and Assemblies Code 562, Electrical Engineering Division of AETD, NASA GSFC

<table>
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<tr>
<th>Project</th>
<th>Dates</th>
<th>Design</th>
<th>Qualification Performance over Harsh Environment</th>
<th>Manufacturing</th>
<th>Integration</th>
<th>Failure Analysis</th>
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<td>ICESAT, GLAS,</td>
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<td>ISS-Express Logistics Career</td>
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Upcoming is the 3<sup>rd</sup> Event in coordination with ESA/CNES/JAXA/NASA on optics for space.

Publications from work noted above can be found @ [misspiggy.gsfc.nasa.gov/photonics](http://misspiggy.gsfc.nasa.gov/photonics)
How Does the Photonics Group Go from Ideas to Flight?

BASIC PRODUCT LIFE CYCLE
Receiver telescopes focused into optical fiber assemblies that route to different detectors. The MLA is aboard MESSENGER currently sending data from Mercury!
The 24 Million Km Link with the Mercury Laser Altimeter

Jay Steigelman
Dave Skillman
Barry Coyle
John F. Cavanaugh
Jan F. McGarry
Gregory A. Neumann
Xiaoli Sun
Thomas W. Zagwodzki
Dave Smith
Maria Zuber

MOLA Science Team Meeting
Bishop’s Lodge, Santa Fe, NM
August 24-25, 2005
Laser Altimeter Observations from MESSENGER's First Mercury Flyby

Maria T. Zuber,1,2 David E. Smith,2 Sean C. Solomon,1 Roger J. Phillips,6 Stanton J. Peale,3 James W. Head III,6 Steven A. Hauck II,5 Ralph L. McNutt Jr.,6 Jürgen Oberst,2 Gregory A. Neumann,1 Frank G. Lemoine,5 Xiaoli Sun,2 Olivier Barnouin-Jha,7 John K. Harmon2

A 3200-kilometer-long profile of Mercury by the Mercury Laser Altimeter on the MESSENGER spacecraft spans 20% of the near-equatorial region of the planet. Topography along the profile is characterized by a 5.2-kilometer dynamic range and 930-meter root-mean-square roughness. At long wavelengths, topography slopes upward by 0.02°, implying a variation of equatorial shape that is at least partially compensated. Crater floors vary in roughness and slope, implying complex modulation over a range of length scales.

Topography is a fundamental measure to characterize quantitatively the surfaces of solid planetary bodies at length scales ranging from the long-wavelength shape to sub-local and regional processes as impact cratering, volcanism, and faulting. During the first flyby of Mercury by the MESSENGER spacecraft on 14 January 2008 (1), the Mercury Laser Altimeter (MLA) (2, 3) successfully ranged to the planet’s surface, providing the first altimeter observations of the planet from a spacecraft.

Previous measurements of the shape and topography of Mercury had been derived from Earth-based radar ranging (4, 5) constrained by range observations from Mariner 10 (6). Because of the low inclination (7°) of Mercury’s orbital plane to the ecliptic, Earth-based altimetric profiles are limited to ±12° latitude and have a spatial resolution of ~6 × 100 km2 and a vertical precision of 100 m. Those observations indicated a planetary reference radius of 2440 ± 1 km, an equatorial ellipticity of 540 ± 54 × 10−6, and an equatorial center of figure (COF) offset from the planet’s center of mass (COM) of 640 ± 78 m in the direction 319.5° ± 6.9° W (6, 7).

The MLA profile (Fig. 1) was acquired approximately along Mercury’s equator, in a region that was in darkness during the flyby, and within the hemisphere not imaged by Mariner 10. Consequently, there are no optical images of the region in which altimetry was collected, so we used an Ancrobo radar image (8) to correlate the profile with surface features. The MLA began ranging ~1 min before the spacecraft’s closest approach and continued for ~10 min. Usable returns were received up to an altitude of 1500 km, which was larger than the expected maximum of 1200 km (2). As the spacecraft velocity and range from Mercury changed during the flyby, the size of laser spots on the surface varied from 23 to 134 m and the shot spacing varied from 888 to 725 m. The vertical precision varied with the received signal strength and was ~<0.5 cm at the closest range, limited by the resolution of the timing electronics. The radial accuracy ~100 m is limited by uncertainties in the trajectory associated with errors in the ephemerides of MESSENGER and Mercury. The profile spans ~20% of the circumference of the planet and shows a 5.2-km dynamic range of topography and 930-m root-mean-square (RMS) roughness (Fig. 1). The radius of Mercury apparently decreases by 1.4 km along the equator from ~10° to 90° E, corresponding to a 0.02° downward slope to the east. This long-wavelength surface tilt begins 30° west of the previously estimated COF/COM offset (6) and was not sampled in Earth-based radar altimetry (6). Such a long-wavelength slope, if a fundamental feature of the equatorial shape of the planet, might arise from crustal thickness or crustal density variations, global-scale mantle density variations, or topography along the planet’s core-mantle boundary, which for Mercury is ~400 km beneath the surface.

The slope can be interpreted in the context of an ellipsoidal planetary shape (10). If we suppose that the difference in principal moments of inertia, B − A, is entirely a result of an ellipsoidal distribution of surface mass with density ρs, and with semi-axes a > b > c, then

\[ B - A = \frac{4π}{15} a b c (a - b) = \frac{8π}{15} R^2 (a - b) \]  

from which we may write

\[ a - b = \frac{2 R}{(B - A/c)} \left( \frac{C_m}{C_e} \right) \left( \frac{60}{π} \right) \rho_s \]  

where A < B < C are the principal moments of inertia of Mercury, C_m is the moment of inertia of the mantle and crust alone, and M_

\[ \text{Fig. 1. (Top) MLA profile (vertical exaggeration 105:1). (Bottom) Ancrobo radar image (adapted from (8)) with MLA profile location (white line) superposed. Arrows at top indicate locations of craters in Table 1. Interpreted from detailed analysis of MLA profile points, the locations of several of the major craters are indicated by arrows on the radar image. The two-ringed circular structure in the Ancrobo image at ~−55 to 60°E is represented in part by a deep depression in the altitude, but north-south radar ambiguities may be contributing to the structure in the image.} \]
The Concept Challenges:

1) LOLA; For the Lunar Orbiter Laser Altimeter (LOLA) Reduce size and weight of previous MLA hardware design from four telescopes into one telescope with fiber based array in a precise compressed pattern.

2) LASER RANGING; For the Laser Ranging Application from Earth,
   - carry the signal from the telescope located on the High Gain Antenna system (HGAS)
   - Traverse three subsystems, to given detector on LOLA, with high reliability and compactness
   - Several interconnections would have to be accommodated for integration subsystem ease.
The Lunar Reconnaissance Orbiter; The Laser Ranging Mission and the Lunar Orbiter Laser Altimeter

Receiver Telescope mounted on antenna and a fiber array to route signal from HGAS to LOLA
Resulting Products Overview

1. Relative range measurements to LRO spacecraft at <10cm precision at 1 Hz

2. Gravity model with sufficient accuracy to calculate knowledge of spacecraft position to within 50 m along track, 50 m cross track, and 1 m radial
   - Requires LR Ranges, S-band tracking data and LOLA Science data
LR Operations Overview

- Transmit 532nm laser pulses at 28 Hz to LRO
- Time stamp Departure and Arrival times

Receiver telescope on High Gain Antenna System (HGAS) routes LR signal to LOLA

LOLA channel 1 Detects LR signal

Fiber Optic Bundle

LR Receiver Telescope
The Solution; NASA GSFC Fiber Optic Array Assemblies for the Lunar Reconnaissance Orbiter

**Lunar Orbiter Laser Altimeter (LOLA) Assemblies**
Description: 5 Fiber Array in AVIM PM on Side A, Fan out to 5 individual AVIM connectors Side B
Wavelength: 1064 nm
Quantity ~ 3 Assemblies Max ~ 0.5 m long

**Laser Ranging (LR) for LRO Assemblies**
Description: 7 Fiber Array on both Sides in AVIM PM Connector
Wavelength: 532 nm
Quantity ~ 9 Assemblies ~ 1 to 4 m long each
<table>
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<th>Document Name</th>
<th>CM Documentation Number</th>
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<td>Preconditioning Procedure for AVIM Hytrel Boots for LOLA fiber optic assemblies</td>
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Qualification Testing on Engineering Models

- Array Compression Testing.
- Thermal Vacuum Workmanship Testing, 8 cycles.
- Vibration Launch Conditions.
- Thermal Cycling with Active Monitoring (accelerated life).
- Cold Gimbal Motion Testing,
  20,000 Mechanical Cycles with Active Monitoring.
- Gimbal Life Testing, 20,000 Motion Cycles.
- Gamma Radiation Testing with Active Monitoring.

Qualification Testing on Flight Models

Array Compression Testing.
Thermal Vacuum Workmanship Testing, 8 cycles.
Vibration Launch Conditions, Instrument Levels.
Qualification of Engineering Models

Random Vibration Testing for EMs

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

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<th>Frequency (Hz)</th>
<th>Protoflight Level</th>
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<tr>
<td>20</td>
<td>0.052 g²/Hz</td>
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<tr>
<td>20-50</td>
<td>+6 dB/octave</td>
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<tr>
<td>50-800</td>
<td>0.32 g²/Hz</td>
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<tr>
<td>800-2000</td>
<td>-6 dB/octave</td>
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<tr>
<td>2000</td>
<td>0.052 g²/Hz</td>
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<td>Overall</td>
<td>20.0 grms</td>
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3 minutes per axis, tested in x, y and z

Both LR and LOLA Assemblies
Thermal Validation Test on 7-fiber LR 400/440um Fiber Bundle
(From -60°C to +60°C at 2°C/min, dwell 30mins at extremes, total 30 cycles)
LRO Laser Ranging Cold Gimbal Motion Life Testing

Gimbals

Window inside gimbal; Flexlite cable inside

Window inside gimbal; Bundle cable inside.

Gimbals w/ single flexlite in thermal chamber

Gimbals w/ bundle in thermal chamber
LRO Laser Ranging Bundle Cold Gimbal Motion Testing Results

End of Test, relative IL ~ 0.50 dB, @ 850 nm, -20°C, 400/440 FV flexlite in Bundle

Gimbal Positions and Optical Insertion Loss@-20C
Fiber #4 @ 850nm with 19295 to 19300 cycles
(Note: The fiber is tight at 0 position and loose at 180)
Radiation Testing and Modeling

\[ A(D) = 1.4516 \times 10^{-4} \phi^{1.0.6412} D^{0.6412} \]
LOLA Integration, October 2007
Gimbal Integration, December 2007
LRO Integration HGAS, 02-2008
Lunar Recon. Orbiter - LRT & HGAS, 02-2008
LRO Integration @ IM Deck, 03-2008
LR Segment 3 Flight Routing, April 2008
Additional Pictures of LRO, June 2008
Integration Complete
LOLA Instrument Team
“It Takes a Village”
2008 New Capability
19 Fiber Arrays with Linear to Bundle Mapping
Conclusion

Do Not Go Where the Path May Lead,
Go Instead Where There Is No Path
and Leave a Trail….

- Ralph Waldo Emerson

Thank you
for the invitation!

For more information please visit the website:

misspiggy.gsfc.nasa.gov/phototonics
NEPP.nasa.gov