

Applications of optical fiber assemblies in harsh environments, the journey past, present and future

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ABSTRACT

Over the past ten years, NASA has studied the effects of harsh environments on optical fiber assemblies for communication systems, lidar systems, and science missions. The culmination of this has resulted in recent technologies that are unique and tailored to meeting difficult requirements under challenging performance constraints. This presentation will focus on the past mission applications of optical fiber assemblies including; qualification information, lessons learned and new technological advances that will enable the road ahead.

Keywords: spaceflight, optical fiber, lunar, connector, mars, ISS, communication, mercury, laser

1. INTRODUCTION

Optical fiber systems have been utilized in space flight hardware for over thirty years.[1] Starting with the first optical fiber passive in flight environmental testing with the Long Duration Exposure Facility in 1978. In 1989 the Cosmic Background Explorer (COBE) satellite, included several photonic and optical fiber components that functioned accurately enough for the Principal Investigators, John C. Mather of Goddard Space Flight Center and George F. Smoot of that mission to become Nobel Prize laureates in 2006.[2] Over the next decade several NASA missions had base-lined optical fiber communication systems including the International Space Station. In 1992 the Small Explorers Program (SMEX) at NASA Goddard Space Flight Center, broke new ground by proving that optical fiber was a viable option for space flight. The SAMPEX, Solar Anomalous and Magnetospheric Particle Explorer was the first mission of the SMEX program which launched in 1992 designed for a 1 year mission duration and is still functional for science data, 16 years later and it utilizes the first GSFC flown optical fiber MIL-STD-1773 communications system as the critical link between the science instruments. In addition to those missions mentioned the following is a summary table that was presented in 1999 at Marshall Space Flight Center as an update after the publication in reference 1 was already released.

Table 1: From 1999, this summary was generated to identify which programs had base-lined optical fiber communications for space flight missions as the link for the critical command and handling data system. For this paper it has been updated to reflect more accurate launch dates

Project Name	Acronym	Launch Date	Technology	Wavelength
Solar Magnetospheric Particle Explorer	SAMPEX	July 1992	MIL-STD-1773,1 Mbps	850 nm
Microelectronic and Photonic Test Bed	MPTB	Dec. 1997	AS1773, 20 Mbps	1300 nm
Microwave Anisotropy Probe	MAP	June 2001	AS1773, 20 Mbps	1300 nm
X-ray Timing Explorer	XTE	Dec. 1995	MIL-STD-1773,1 Mbps	850 nm
Hubble Space Telescope, upgrades	HST	Feb. 1997	MIL-STD-1773,1 Mbps	850 nm
Photonic Space Experiment	PSE	proprietary	MIL-STD-1773,1 Mbps	850 nm
Tropical Rainforest Measuring Mission	TRMM	Nov. 1997	MIL-STD-1773,1 Mbps	850 nm

Over the decade to follow more varied applications of optical fibers were utilized at NASA Goddard Space Flight Center for science instrumentation. In addition to what is listed above, the International Space Station managed by Johnson Space Center, used a Boeing designed optical fiber data bus called the High Rate Data Link using 1300 nm graded index multimode optical fiber links and an enhanced MIL-STD-38999 connector with MIL-T-29504 termini. The MIL-STD-

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1773 optical fiber links typically used the MIL-STD-38999 and MIL-T-29504 termini where in other cases the customized 140 micron Johanson FC type connector was used. This connector is no longer recommended for new space flight missions since Johanson has sold the optical fiber products line. The cables that were used during those missions is also obsolete and no replacement to the exact dimensional specifications of the GSFC qualified Brand Rex OC1008 or the International Space Station's version of the Brand Rex OC1416. However, the study towards finding a suitable replacement is underway.

In addition to the projects mentioned above, the Code 562 Photonics Group at NASA Goddard Space Flight Center, has been involved in a variety of optical fiber system implementations over the past decade since the MIL-STD-1773 decade. The following is a summary table of how we have enabled flight hardware and how.

Table 2: NASA Goddard Space Flight Center Photonics Group Heritage with Space Flight Optical Fiber Subsystems over the past decade.

Project	Dates	Design	Qualification Performance over Harsh Environment	Manufacturing	Integration	Failure Analysis
ICESAT, GLAS,	1997 - 2005	X	X	GSE		Prototype
ISS	1998 - 2008					Vendor/ Flight
ISS - HDTV	2003	X	X	FLIGHT		
Fiber Optic Data Bus	1997 -2000	X	X			
Messenger – MLA,	2001 - 2004	X	X	FLIGHT	X	
Sandia National Labs (DOE)	1998 -2008		FLIGHT			Vendor/ Flight
ISS-Express Logistics Career	2006 -2009	X	X	FLIGHT	X	
Air Force Research Lab	2003, 2008		X			
Shuttle Return To Flight	2004 -2005			FLIGHT		
Lunar Orbiter Laser Altimeter	2003 -2008	X	X	FLIGHT	X	Prototype
Mars Science Lab ChemCam	2005 -2008	X	X	FLIGHT	X	Vendor
Laser Ranging, LRO	2005 - 2008	X	X	FLIGHT	X	Prototype
Fiber Laser IIP/IRAD	2003 - 2006	X	X	QUAL		
ESA/NASA SpaceFibre	2008 (TBD)		X	QUAL		

GSE = Ground System Equipment Assemblies Support
FLIGHT = Actual flight hardware was the subject material.
Vendor = Vendor supplied hardware

In Table 2 the project name or acronym is listed with the dates of development and the identification of which type of services were performed by the group. In the events that the Photonics group was requested to perform failure analysis during the late stages of integration the root cause was usually a lack of failure mode risk mitigation during the design/development process, quality documentation or handling issues. Most concepts are born from a creative design group who know more about how to capture science data and less about the intricacies of space flight material choices and how to implement appropriate risk mitigation techniques and keep an effective schedule. Too many times we have found that vendors and contractors that make space flight hardware deliveries did not invite well versed failure mode physicists and engineers to the design table. What followed later was that the optical fiber assemblies were viewed similar to copper wire cable harnessing instead of micro-optical devices. This fallacy has led to many issues during integration that span from design to handling during flight integration.

2. DISCUSSION OF OPTICAL FIBER SUBSYSTEMS

2.1 Development of subsystems for harsh environments

Based on the extensive work over the past decade related to flight builds and failure analysis of other providers that are not in the high volume production of space flight hardware, the group has development flow from concept to delivery.

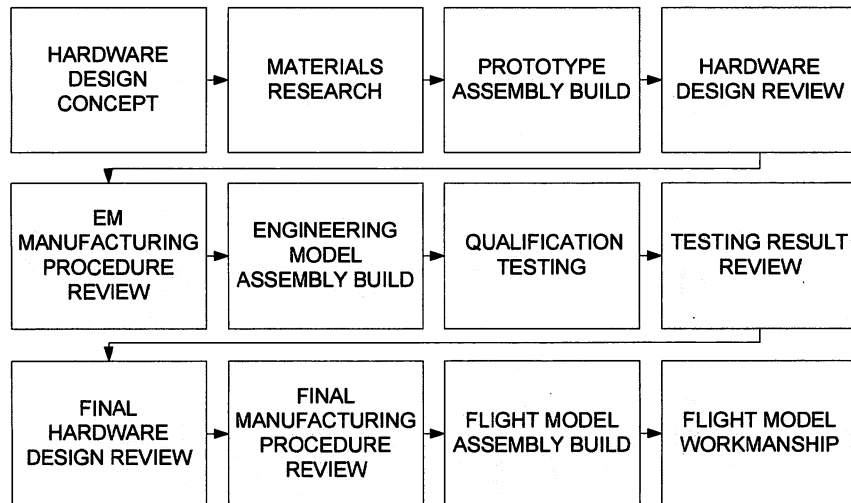


Figure 1: Photonics Group Concept to Delivery Flow

Our approach was developed by years of experience and an understanding of risk mitigation for failure modes vs. schedule for typical space flight projects--and the fact that nearly all new technologies are commercial off the shelf and must be tested and developed as such in order to achieve the least amount of anomalies by the time flight manufacturing begins. A long list of quality documentation from unique developmental endeavors is required for mission success, whether it be from a vendor or another government manufacturing provider.

2.2 Approach to Commercial Technologies

Something engineering designers are wise to keep in mind is the following; being well educated about the physics of failure is not always feasible for vendors that can not afford to pay the bill to go through extensive testing as they once did for the military for compliance to the military specifications. This is essentially what the space flight development engineer is doing when specifying to a vendor that they must comply with a long list of Military Standards. There is no incentive for a vendor to use precious resources to extensively test their commercial components to a set of unusually harsh environmental parameters when the customer is only going to purchase a few on a one time, one-of-a-kind instrument.

The expectation that a vendor is obligated to meet a large amount of difficult demands for a space flight customer for the purpose of stating that this partnership exists, is not beneficial to the vendor in producing the business it would take to justify the costly expenditure. It is important that even the component engineers understand that to achieve high reliability that they, themselves need to be responsible for making that happen between analysis and testing and working very closely with the vendors to provide guidance that will enable success.

Most commercial processes that are designed for high volume, can not be changed to accommodate a space flight build of a particular component, therefore the analysis especially with regards to processes and construction can lead to suggestions to the vendor however, do not expect that if the process change involves extra money spent on the part of the vendor its not likely going to be feasible and if it is it will no doubt result in a very costly non-recurring engineering fee that the space flight program will need to fund. The old saying "you can get a cheap job done but it won't be good or you can get a good job done but it won't be cheap" needs to be considered when approaching the commercial industry

about using commercial parts in space. Many vendors are even going away from compliance with the Telecordia certifications since the majority of their customers today are not commercial telecommunications providers but are industrial customers using light for manufacturing of their products. Even if a part was originally part of the telecommunications components base 7 years ago, you may be surprised to find that the same exact part being produced today is no longer being tested to Telecordia standards even if it was in the past.[5]

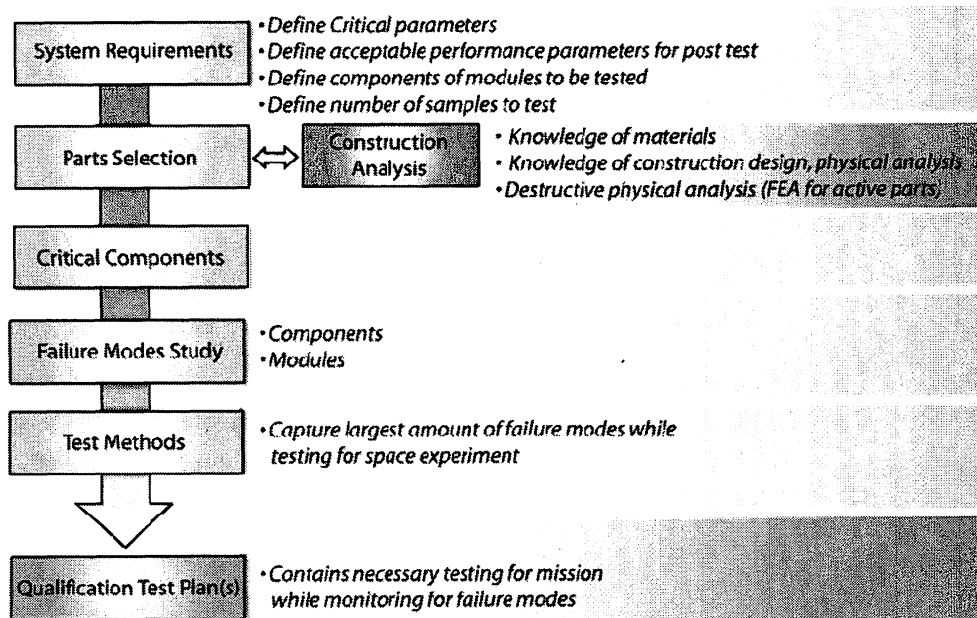


Figure 2: Steps to a Qualification Test Plan; NEPP Technology Assurance Approach [6]

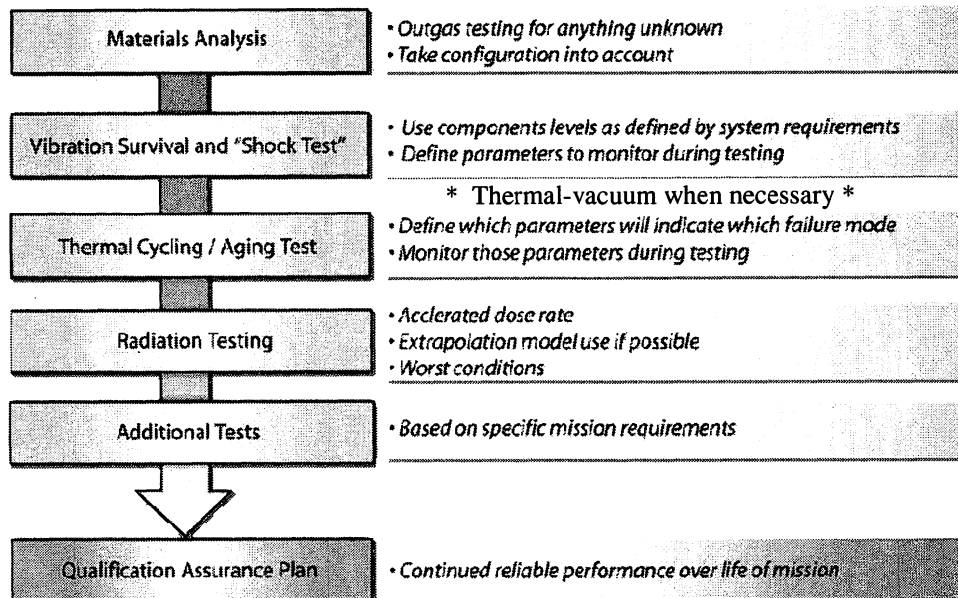


Figure 3: COTS Qualification Plan Approach [6]

Figures 2 and 3 summarize the steps in development of reliable commercial optical fiber assemblies and then how to qualify or perform requirements validation on the engineering models such that the flight models will be ready for the mission. Reference 5 presents a more comprehensive explanation of the details. Many of those details are reflected in the product flow of Figure 1. If there is one key item of note from the above figures it would be; having a good understanding of how materials affect other materials when performing packaging of optical fiber hardware can save a great deal of funding later in development and integration.

3. FLIGHT EXAMPLES AND CURRENT TECHNOLOGY

In the last decade two connector types have emerged as harsh environments, the USConec MTP array connector type for parallel communications using multimode ribbon fiber and the Diamond AVIM DIN type connector with active alignment for single or multimode applications. The Diamond AVIM was qualified for flight applications back during the mid 1990's by Lockheed Martin [7] and continued to be used and qualified by NASA and ESA.

The first time NASA Goddard used the AVIM connector was for single and multimode interconnections on the Ice, Cloud, and land Elevation Satellite (ICESAT) GeoScience Laser Altimeter (GLAS). Four different types of fiber were used, two types of multimode and two types of single mode. In addition, a 2 kilometer single mode optical fiber delay line used for on orbit calibration.[8] During the development of GLAS, several optical fiber candidates were tested for radiation induced scintillation effects and no results that would effect performance were detected.[9] The standard AVIM connector continued to be used on the Mercury Laser Altimeter, Shuttle-Return-to-Flight High Definition heat tile sensor camera.

The MTP connector was developed for communications applications and to be compatible with the newly available Vertical Cavity Surface Emitter Laser (VCSEL) technology that arrived in the mid 1990's. The first NASA GSFC mission scheduled to fly this connector was the Spaceborne Fiber Optic Data Bus (FODB). Several qualification studies on the connector and cable assembly were conducted for NASA and the Department of Energy and published in the past decade. [10-12]

3.1 The Mercury Laser Altimeter (MLA)

The MLA was a laser altimeter launched in 2004 to measure the topography of Mercury. As part of the receiver optics system, four individual step index multimode fiber were linked from the receiver optic telescopes to the MLA individual detectors. The AVIM connector with FLEXLITE cable from W.L. Gore was used to provide the optical fiber links. For the instrument. The requirements validation testing was conducted prior to flight manufacturing and published in reference 13.

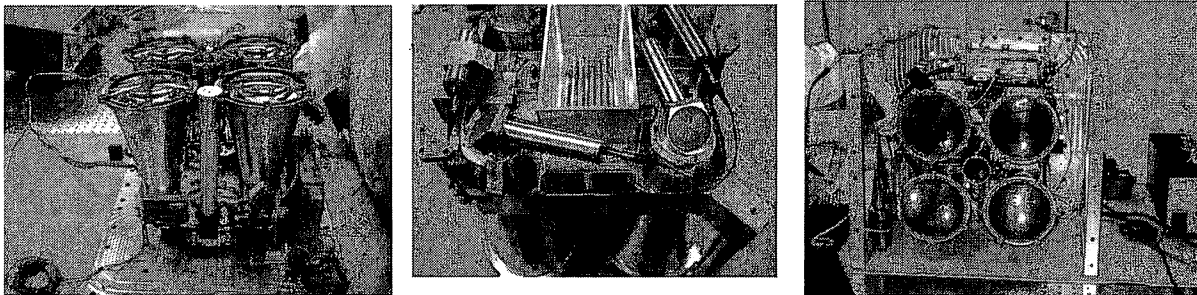


Figure 4: The Mercury Laser Altimeter consisted of four telescopes with fiber coupled form each to four individual detectors.[13]

An experiment that was conducted with the Mercury Laser Altimeter in May 2005, provided the assurance that laser communications could traverse long distances through space. A laser system built and designed at GSFC called "HOMER" [14] located at NASA's Goddard's Geophysical and Astronomical Observatory was used to contact the MLA aboard MESSENGER on its way to Mercury and established a ranging link across 24 million kilometers. [15-16]. This gave the Principal Investigators new insight into what was possible. This will be discussed later when the subject of the Lunar Reconnaissance Orbiter (LRO) adds a laser ranging capability to the instrumentation already planned.

3.2 The Lunar Orbiter Laser Altimeter on LRO

The Lunar Orbiter Laser Altimeter is part of the instrument suite on the Lunar Reconnaissance Orbiter and where the Mercury Laser Altimeter consisted of four telescopes and is designed to be capable of measuring with a 0.5 m precision, LOLA will consist of only one telescope and provide a 0.1 meter precision. Both altimeters were designed to function using pulsed 1064 nm lasers and measure the timing of the reflections with short duration pulses. LOLA uses a diffractive optical element to split a single laser beam into five separate pulsed beams with five very precisely positioned optical fibers behind the receiver optics to link each beam to its designated detector. The time of flight measurements

provide ranging information, the pulse spreading corresponds to surface roughness, and the return energy provides surface reflectance. The five spots will provide slopes along and across the orbit track. [17] In addition, one of LOLA's detectors will be used to monitor the laser ranging signals received by a 532 nm pulsed laser from the NASA Goddard Greenbelt facility. Figure 4 shows the flight instrument next to an artist's rendition of the LOLA instrument and the LRO.

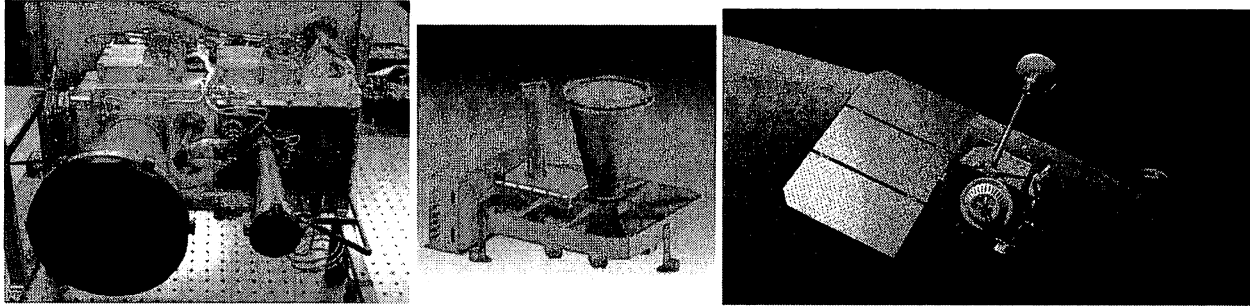


Figure 4: a) LOLA flight instrument, b) artist's drawing of LOLA instrument, c) artist's drawing of LRO.

In order to enable the five spots reflected back to the instrument a fiber array was developed and is first in the world of its type since the entire array is packaged into a single polarization maintaining type Diamond AVIM connector. Figure 5 shows the endface pattern of all 5 200/220 micron step index optical fibers in a tightly tolerance pattern along with a picture of one of the LOLA flight assemblies.

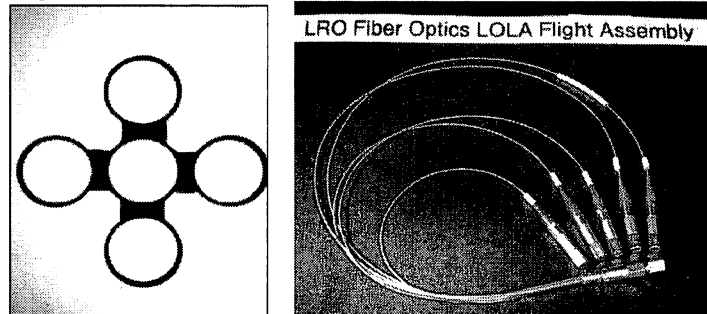


Figure 5: a) LOLA array 200X magnification view of the the optical fiber connector endface, b) the LOLA flight bundle array.

In order to assure of high reliability for this application, many qualification tests were conducted and the results of which are contained in reference 18. As a result of the qualification testing, the flight procedures were rewritten and once again test articles were retested to qualification levels. For LOLA, the 20 grms acceleration profile was used to qualify the engineering models. For flight a smaller acceleration profile was used for workmanship purposes. Figure 6 shows the production testing flow required for the LOLA flight hardware as a result of qualification testing.

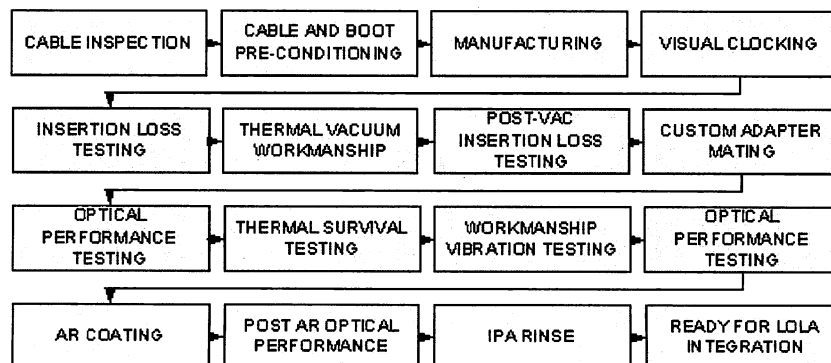


Figure 6: LOLA Optical Fiber Bundle Array Assembly Delivery Flow

This assembly is the first of its kind to be fully qualified for harsh environments and integrated into a single connector on a flight instrument. The LOLA flight assembly integrated to the instrument was tested for three times for random

vibration 1) protoflight workmanship, 2) instrument level qualification and 3) LRO space craft level qualification. The flight assemblies passed all tests.

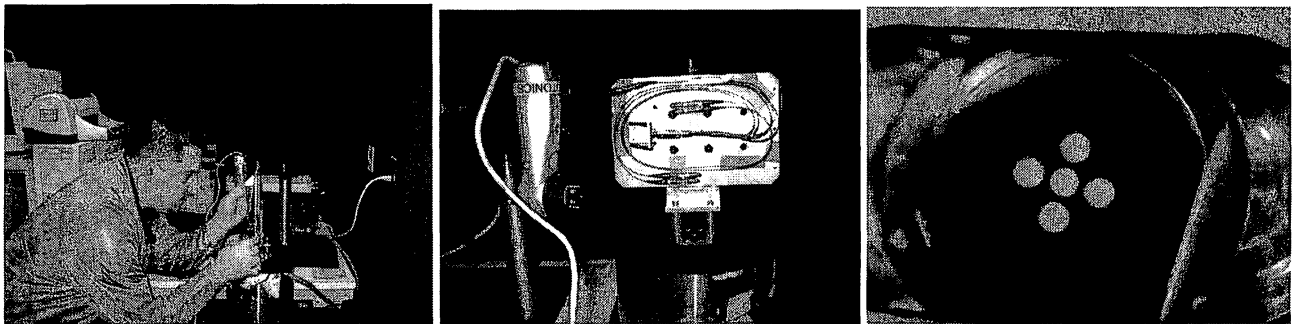


Figure 7: LOLA flight workmanship random vibration testing a) Frank LaRocca performs vibration testing, b) LOLA flight article on the vibration fixture, c) flight assembly final inspection post vibration testing

3.3 Laser Ranging on the LRO

After the success of ranging with the MLA, the “Laser Ranging” project was added to the LRO mission instrument suite. A small telescope was mounted to the High Gain Antenna System (HGAS) on the LRO and required an optical link from behind the telescope across the HGAS gimbals, down its boom, around the deployment mandrel and across the space craft to LOLA detector channel 1. Figure 8 illustrates the concept.[19]

LR Operations Overview

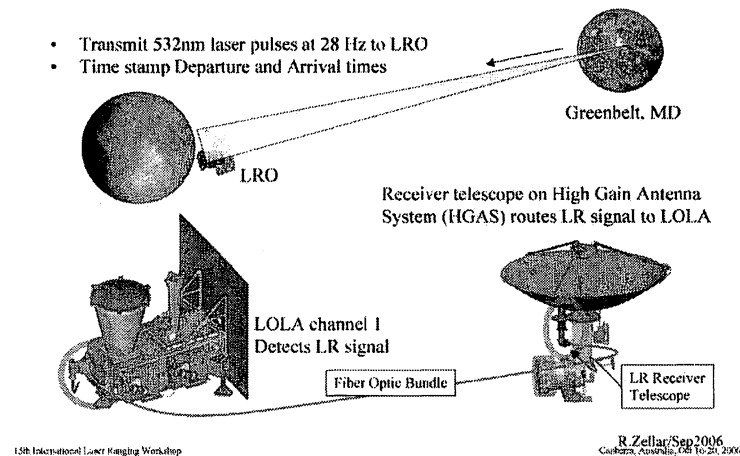


Figure 8: Laser Ranging operations summary

Figure 10 diagrams the flight system components. To complicate matters two interconnections were required; one at the interface between the steering HGAS gimbals and one after the boom deployment mandrel at the space craft. The solution to the challenge was developed by the Photonics Group at NASA GSFC to be a seven optical fiber array bundle assembly set approximately 10 meters long. Figure 9 shows the unique hardware used for this application and reference 20 presents the qualification data for the engineering models. Reference 21 contains the information regarding integration of the flight hardware. Early on in the development process, the cold requirement was being held at -75°C . This requirement was incorporated into the choice of using stainless steel 416 instead of the stainless steel 303 material we had originally planned to use. Even though the thermal requirements were later altered based on thermal conducting tape being used for control, survival testing was conducted down to -75°C to assure survival of the assemblies and the assemblies passed all qualification testing with nominal changes in performance.[20] Another difficult requirement for the team was the way in which the fiber cables would be routed through the HGAS gimbals. Essentially the gimbals

contain cable wraps that coil and uncoil the cables to enable the rotation of the antenna for beam steering. Material selection and material compatibility was an enormous issue during development.

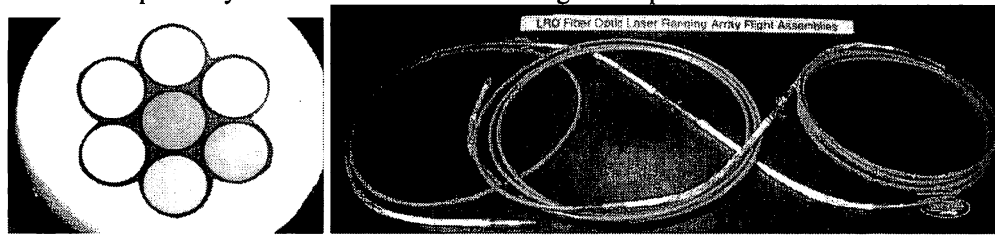


Figure 9: LRO Laser Ranging Assemblies

LR Flight System Components

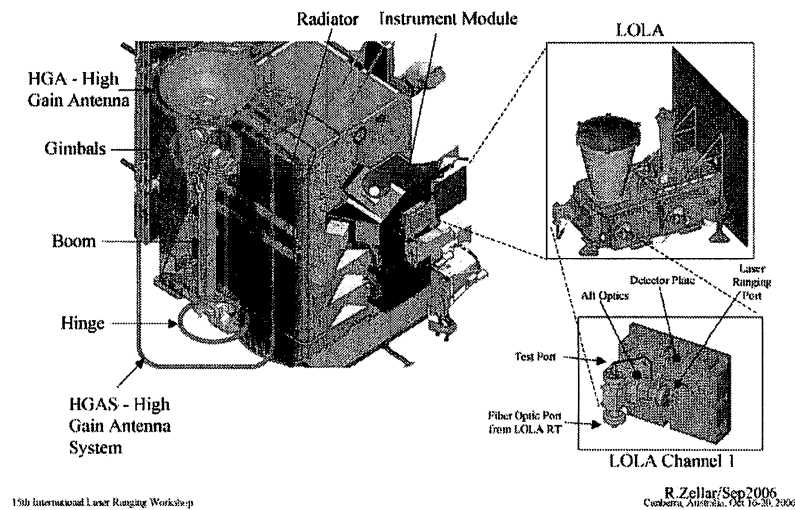


Figure 10: Laser Ranging flight components for optical fiber linkage.

As mentioned previously, documentation is a key item to ensure reliability of the flight hardware. Table 3 lists the documentation required for the Laser Ranging optical fiber bundle assemblies.

Table 3: Quality documentation for the Laser Ranging Flight Assemblies.

Document Title	Document Number
Thermal Pre-conditioning on Flexlite 200/220 μm fibers for flight application	LOLA-PROC-0137
Preconditioning Procedure for AVIM Hytrel Boots for LOLA fiber optic assemblies	LOLA-PROC-0138
Diamond AVIM PM Kit Pre-Assembly Inspection	LOLA-PROC-0104
Ferrule Polishing & Ferrule/Adapter Matching Procedure	LOLA-PROC-0139
Assembly and Termination Procedure for the Laser Ranging Seven Fiber Custom PM Diamond AVIM Array Connector for the Lunar Reconnaissance Orbiter	LOLA-PROC-0112
Compression Test Procedure for Fiber Optic Connector	LOLA-PROC-0141
Active Optical Power Optimization Procedure for The Laser Ranging Optical Fiber Array Assemblies	LOLA-PROC-0110
Laser Ranging Fiber-Optic Bundle Optical Test Procedure	LOLA-PROC-0107
Insertion Loss Measurement Procedure for The Laser Ranging Optical Fiber Array Bundle Assemblies	LOLA-PROC-0111
Mating of Two LR 7-Fiber Optical Fibers Using Cleanable Adapter	LOLA-PROC-0142
Cutting Back The Kynar Strain Relief For Integration	LOLA-PROC-0143
Fiber Optic Bundle Inspection and Insertion Loss Measurement	LOLA-PROC-0148

The flight assemblies have been integrated to the space craft and have passed all qualification testing. LRO is scheduled for launch later this year.

3.4 Mars Science Laboratory ChemCam

For the Mars Science Lab, the ChemCam the Photonics Group in cooperation with Jet Propulsion Laboratory (JPL) team: Chris Lindensmith, Charles Hays, Richard Rainen, Edward Miller and Principal Investigator Roger Weins from Los Alamos National Labs developed optical fiber assemblies for the integration. Once again, as with LRO the mission the mechanical requirements included routing the optical fiber assemblies through moving gimbals and down a boom. During the early stages of development the MSL thermal requirements for the ChemCam assemblies were -143°C for survival lower limit and $+110^{\circ}\text{C}$ for the high limit. The high thermal survival temperature was set to accommodate a decontamination vacuum bake-out that would be necessary for all MSL hardware.

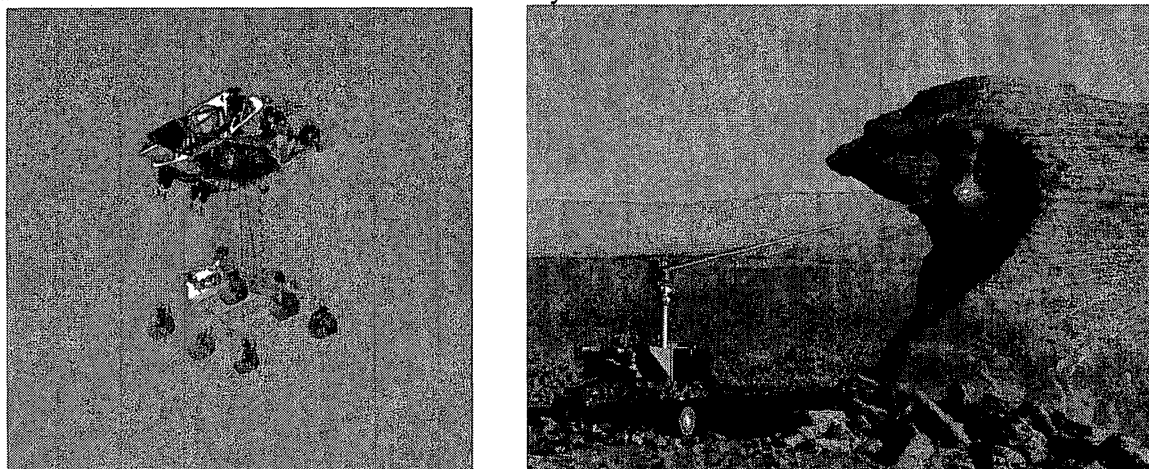


Figure 11: Artists rendition of Mars Science Lab ChemCam[22]

While thermal bake-outs are considered a typical protocol for all space flight instrumentation the thermal limit on the hot end of the spectrum is usually less. Again, for its superior thermal performance the AVIM connector along with the W.L. Gore FLEXLITE cable were the parts of choice for another unique application. Some qualification testing was conducted by the Photonics Group of GSFC while other tests were conducted at JPL. By the time thermal life testing started the requirements had changed to -55°C to $+50^{\circ}\text{C}$, with the high temperature bake-out still to occur at $+110^{\circ}\text{C}$.

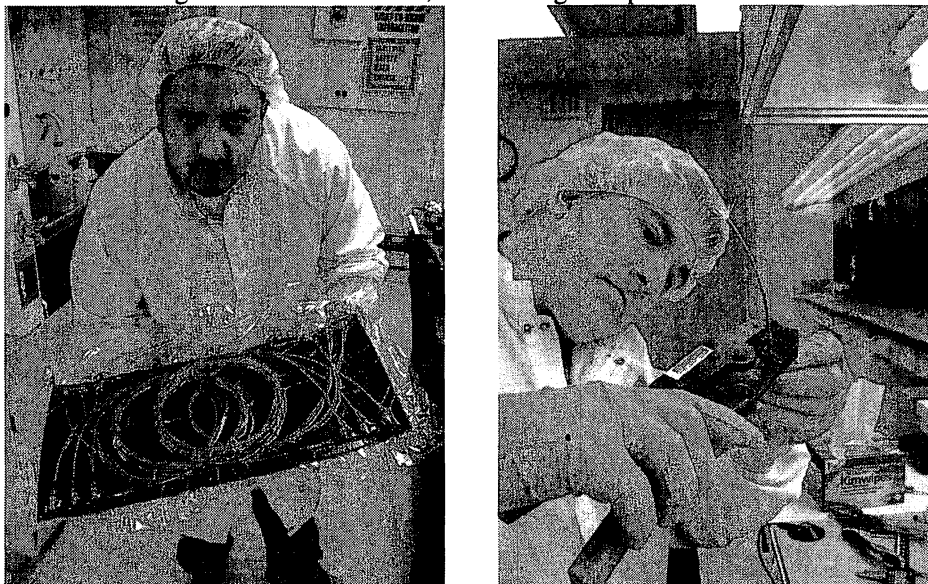


Figure 12: Frank LaRocca and Richard Chuska manufacture and deliver the flight optical assemblies for MSL.

Again, as with LRO, the lower limit of the survival thermal range was controlled through the use of neptape for conductive heating. The quality documentation was extensive and presented in Table 4.

Table 4: The quality documentation for manufacturing and delivery of the ChemCam optical fiber assemblies.

Document Name	562-PHOT-QAD-MSL-FON1482-INSP
Optical Cable Inspection	562-PHOT-QAD-MSL-THERM-PC
Cable Thermal Pre-Cond	562-PHOT-WOA-MSL-BOOTS
Polymers Degas	562-PHOT-QAD-MSL-RAD (12-day worst-case cobalt60 radiation testing)
Mission Survival Radiation Total Dose Testing	562-PHOT-QAD-MSL-VIBE (7.9grms to 14.4grms step-up vibration on selected samples)
Mission Survival Vibration Qualification	562-PHOT-QAD-MSL-THERM-CYCLE (100+ cycles including planetary bake-out)
Mission Survival Thermal Cycling Testing	562-PHOT-QAD-MSL-MAN-92 (Patch Cables)
FC Cable Manufacturing (non-flight)	562-PHOT-QAD-MSL-MAN-92-332 (Prototype Development)
AVIM Cable Manufacturing (non-flight)	562-PHOT-QAD-MSL-MAN-332-EM (Eng Models)
AVIM Cable Manufacturing (flight-like)	562-PHOT-QAD-MSL-MAN-332-FM (FLIGHT and FLIGHT Spares)
AVIM Cable Manufacturing (FLIGHT)	562-PHOT-QAD-MSL-INS-92-332
Insertion Loss Testing (All-Cables)	562-PHOT-QAD-MSL-WKM-92-NONFL (Non-flight workmanship)
Non-flight Cable Workmanship Testing	562-PHOT-QAD-MSL-WKM-332-FLIGHT (FLIGHT workmanship)
FLIGHT Workmanship Testing	GSFC-PHOTONICS CABLE TRAVELER REV 080101
MSL CABLE TRAVELER	GSFC-PHOTONICS ENGINEERING DOCUMENT REVIEW
Engineering Documents Review	GSFC-PHOTONICS PRE-SHIPMENT PROCEDURE CHECKLIST
Pre-Shipment Inspection Checklist	GSFC-PHOTONICS PACKING PROCEDURE CHECKLIST
Cable Packing Procedure Checklist	562-PHOT-QAD-MSL-FON1482-INSP

The Mars Science Lab is scheduled to launch in 2009.

3.5 Express Logistics Carrier on International Space Station.

The Express Logistics Carrier is being developed as a “smart” warehouse for the International Space Station. The communication “brains” of the warehouse or the Flight Control Unit (FCU) will be transmitting data to and from the ISS. The FCU will provide: remote terminal to the ISS, bus controller for up to two science experiments, command distribution and telemetry collection for up to two science experiments, ethernet to High Rate Data Link (HRDL) playback of science data experiments, command distribution and telemetry collection for the Experiment Control Module and the Power Module. The High Rate Data Link (HRDL) is an optical fiber communications bus developed for ISS by Boeing. The transceivers for the optical fiber communication for the ELC FCU communications with the HRDL are being manufactured by Space Photonics Incorporated. Space Photonics or SPI originally worked under the company name of Optivision over ten years ago as the transceiver provider for the Space Borne Fiber Optic Data Bus also known as FODB. The MTP connector was qualified for the maiden voyage of this communications system but the flight for FODB was cancelled during qualification testing of the subsystem components due to instrument re-scoping on Earth Orbiter 1.

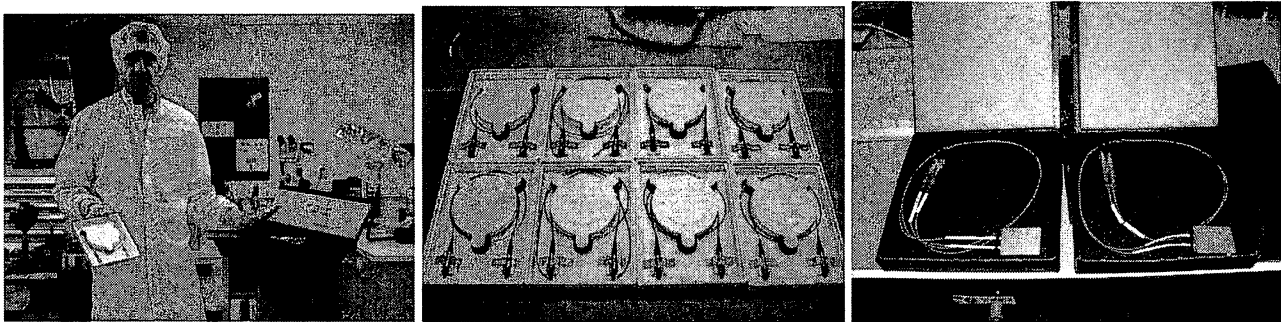


Figure 13: a) Robert Switzer holds the manufactured assemblies b) optical fiber assemblies for the SPI transceiver ready for shipment, c) SPI transceivers with the optical fiber pigtails packaging completed.

The standard AVIM with custom drilled pilz ferrules and FLEXLITE combination was selected for the SPI transceivers and manufactured by the Photonics Group. The fiber had to match that of the ISS HRDL and therefore was 100/140 micron graded index optical fiber manufactured by Nufern. At time the engineering models are being tested for

compatibility with the HRDL system before the flight models will be built. The remaining cable harnessing will be built by the photonics group using the ISS custom cable still in supply and the ISS version of the MIL-STD- 38999 with MIL-T-29504 termini with hybrid assemblies to fan out the 38999 terminations to the AVIM adapters at the FCU interface.

4. FUTURE MISSIONS AND TECHNOLOGIES

It is expected based on current requests that single connector arrays will continue to be in high demand due to the successful development of the custom array bundles developed for both LOLA and Laser Ranging on LRO. No longer will designers be constrained by having the receiver detectors near the transmitters. Fiber lasers are a viable technology for harsh environments and terminations will be necessary to accompany those. The NASA Photonics Group continues to encourage emerging technologies through development efforts for flight projects and through evaluation programs of vendor provided technologies through the NASA Parts and Packaging Program.

The MTP is expected to continue as a viable option for multimode communications. The group is continuing the evaluation of this connector to provide greater thermal stability of the MTP terminations since the “how” of an optical fiber assembly procedure is just as important as the “what” of an optical fiber assembly.

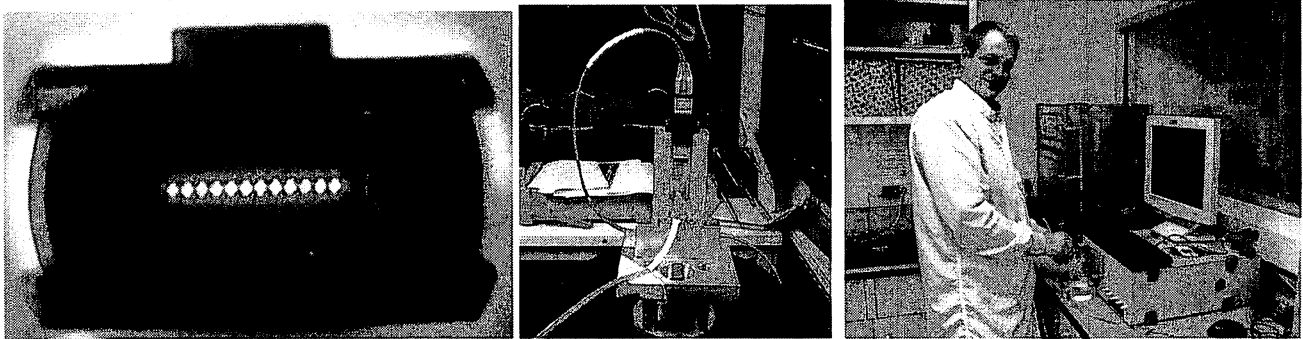


Figure 14 a) MTP connector endface, b) an MTP interconnection begin evaluated for vibration performance, c) Joe Thomes conducts insertion loss testing on the MTP assemblies for a DOE qualification study.

In addition to the MTP connector for communication purposes, science instruments will still require arrays of various types for moving light from one location on the instrument to another. Single connector arrays tailored to a variety of harsh environments and remote locations will continue to be of interest.

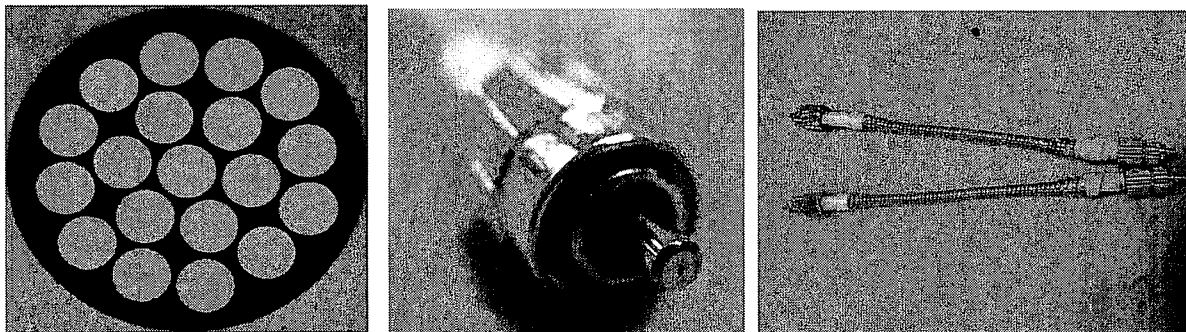


Figure 15: a) 200 X magnification of a 19 optical fiber array end face ferrule in an FC connector, b) Close up of FC ferrule and connector, c) 19 fiber custom array technology.

Currently the group is developing new capabilities in the areas of customized arrays, high power terminations for fiber laser and laser transmission systems and high performance small form factor configurations for board interconnects.

CONCLUSION

The Photonics Group will continue to develop and evaluate various technologies for the upcoming missions identified in the NASA Decadal survey [23], interconnection for small form factor applications and for high performance and

reliability missions such as the outlined for Constellation. We provide guidance to vendors for their flight builds as well as providing small volume customized versions for instrumentation and communication systems for vendors and other government agencies. Although commercial versions of the technologies described here may exist, most vendors and agencies still require specialized guidance especially with regards to the physics of failure when building high performance and high reliability optical subsystems for harsh environments.

ACKNOWLEDGEMENT

The group would like to thank all those who make our work successful: Marcellus Proctor, Jelila Mohammed, Patricia Friedberg, Kusum Sahu, John Day, Fred Huegal, Robert Lehair, Henning Leidecker, Adam Matuszeski, Mark Flanagan, Matt Showalter, Steve Schmidt, Luis Ramos-Izquierdo, John Cavanaugh, Denise Radliff, Bruce Meinhold, Amir Sadeghi, Darryl Lakins, Craig Tooley and Cathy Peddie (LRO Program Managers), the MSL team: Edward Miller, Chris Lindensmith, Richard Rainen, Charles Hayes, Roger Weins, Joe Mooney and Cheryl Provost from CeramOptec, W.L. Gore, Frederick Taugwalder from Diamond Switzerland, Diamond USA, Polymicro Technologies, Martin Seifert at Nufern, Sandia National Labs, Frank Hung, Jeffery Christiansen, Fred Orlando, Charles Chalfant, and Matt Leftwich from SPI, the ELC team Chris Smith, Oscar Gonzales, Ali Feizi, and most of all Ken LaBel and Mike Sampson (NEPP program managers) for funding the dissemination of this work.

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