Optical Fiber Assemblies for Space Flight from the NASA Goddard Space Flight Center, Photonics Group

Melanie N. Ott[a1], William Joe Thomas[b] Frank LaRocca[b]
Richard Chuska[b], Robert Switzer[b] , Lance Day[b]
[a]NASA Goddard Space Flight Center, Greenbelt Maryland, 20771
[b]MEI Technologies, 7404 Executive Place, Suite 500, Seabrook, MD 20706

ABSTRACT

The Photonics Group at NASA Goddard Space Flight Center in the Electrical Engineering Division of the Advanced Engineering and Technologies Directorate has been involved in the design, development, characterization, qualification, manufacturing, integration and anomaly analysis of optical fiber subsystems for over a decade. The group supports a variety of instrumentation across NASA and outside entities that build flight systems. Among the projects currently supported are: The Lunar Reconnaissance Orbiter, the Mars Science Laboratory, the James Webb Space Telescope, the Express Logistics Carrier for the International Space Station and the NASA Electronic Parts and Packaging Program. A collection of the most pertinent information gathered during project support over the past year in regards to space flight performance of optical fiber components is presented here. The objective is to provide guidance for future space flight designs of instrumentation and communication systems.

Keywords: space flight, optical fiber, lunar, connector, mars, ISS, communication, laser, array

1. INTRODUCTION

Towards the goal of providing as much information where possible to the space flight engineering community, the Photonics Group publishes characterization studies and pertinent conclusions regarding currently available commercial technologies for harsh and space environments each year. Typically this is performed in service to the NASA Electronics Parts and Packaging Program [1] which provides funding for information dissemination of evaluation data and conclusions regarding commercial components hardware with flight potential.

In an environment of constant industry change as a result of global economy destabilization, acquiring reliable commercial components is more challenging than ever. Due to the need for enhanced scientific and communication systems and the need to use current technology produced by industry, it is imperative to focus on environmental characterization and risk assessment of current technologies with greater intensity . Finding the balance between risk assessment for high reliability missions while component companies are experiencing fluctuations of ownership and processes, is key to reducing the risk of using the components necessary to meet high performance requirements. The Commercial-Off-The-Shelf (COTS) approach for risk assessment provides the best opportunity for achievement. [2]

In a variety of cases it is adequate to utilize commercial products in space flight hardware using the prescribed method outlined in reference 2 while paying strict attention to upfront materials analysis and rigorous quality documentation record keeping. In other cases, where no product existed or could be developed in industry due to the extensive knowledge required or lack of business interest, unique flight subassemblies are built by government or government funded institutions. In cases where government does produce subassemblies it is common to find commercial components used with rigorous quality practices. Such was the case for the array assemblies developed, manufactured and integrated by the photonics group for several applications on the Lunar Reconnaissance Orbiter. [3-4]

[1] Melanie.n.ott@nasa.gov, +1-301-286-0127, http://photonics.gsfc.nasa.gov

2. DISCUSSION

2.1 The Lunar Reconnaissance Orbiter (LRO)

Many publications have been written regarding the careful development of the seven optical fiber array assembly for the Laser Ranging application on LRO.[3,4] In addition, more information regarding the incentive for providing the LRO with a functional ranging system are in references [5] and [6]. It is discussed in those publications how a two way laser link was established between the ground station at NASA GSFC and the Mercury Laser Altimeter on Messenger to make history with the longest laser link ever established in space. In reference [8] the full experiment to provide ranging information from the earth based station to LRO is discussed at the system level. Although many of the techniques used on the experiment were clever manipulations of existing technologies, the optical fiber bundle array was the unique technology designed and developed just for the instrument and this had never been accomplished in previous space flight designs world wide. The link was designed to transmit the light from the Laser Ranging receiver telescope, around cable wraps in gimbals, down a boom, around a deployable mandrel, and across the space craft to a detector on Lunar Orbiter Laser Altimeter. The entire distance was 10 meters with two interconnection points where array cables were mated together to complete the optical transmission path as subsystems were integrated together. One such point existed between the High Gain Antenna steering gimbals and the other was at the interface of the boom mandrel and the space craft body. The details of the design and routing are in reference [3].

The team was given 18 months schedule time to journey from an on-paper concept to flight hardware integration. To accomplish this, environmental testing was conducted in parallel with development and flight builds. Post flight build testing was conducted on flight like models to ensure that subsystem movement and environmental exposure of the systems would not inhibit the assembly from performing within specified parameters. For example, the gimbal movement test had to be conducted several times during the duration of the development. The first gimbal motion validation was conducted with a single stand of optical cable during cold temperature exposure. The second gimbal/cable test was conducted at cold temperature, with the first cable model for the seven fiber bundle. This first bundle engineering model was determined to be below expected performance at bench level testing. The lack of adequate transmission was due to the cable configuration as manufactured. The cable was once again fabricated with a slight change of design for flight use. The third test to perform on the final flight design was conducted post flight gimbal integration and was a long term gimbal life test. The new design had improved transmission but there was a question as to whether increased transmission would result in less stability during movement. The results of the last gimbal life test are included here.

2.1.1 The Final Gimbal Life Test for the 7 Optical Fiber Bundle

The seven optical fiber cable and end face pictures are in Figure 1. Three assemblies made up the entire set that are similar to the assembly picture in Figure 1.

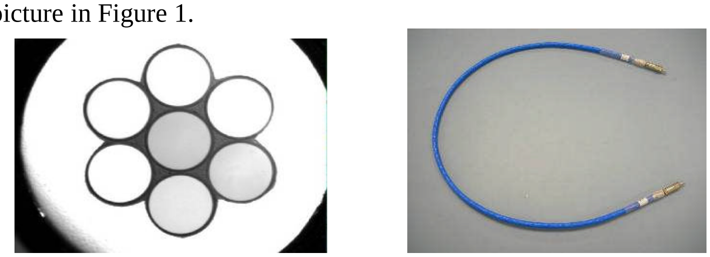

Figure 1: Laser Ranging Seven Fiber Array a) End Face Geometry at 200X, b) example of bundle assembly.

In Figure 2 the gimbal set up is shown. All seven channels were monitored actively during motion of the gimbal throughout life testing. In previous cases the channels were monitored individually for assurance that no slow cracking was occurring in any of the individual optical fibers. During this test, all channels were monitored as a bundle. We were fairly certain that this test would only be conducted as a formality. The previous version represented a much more highly stressed condition for the individual optical fibers in the assembly due to the localized twisting of them around the center Teflon core. The bundle was monitored with 532 nm light and the source variability was removed from the in-situ data.

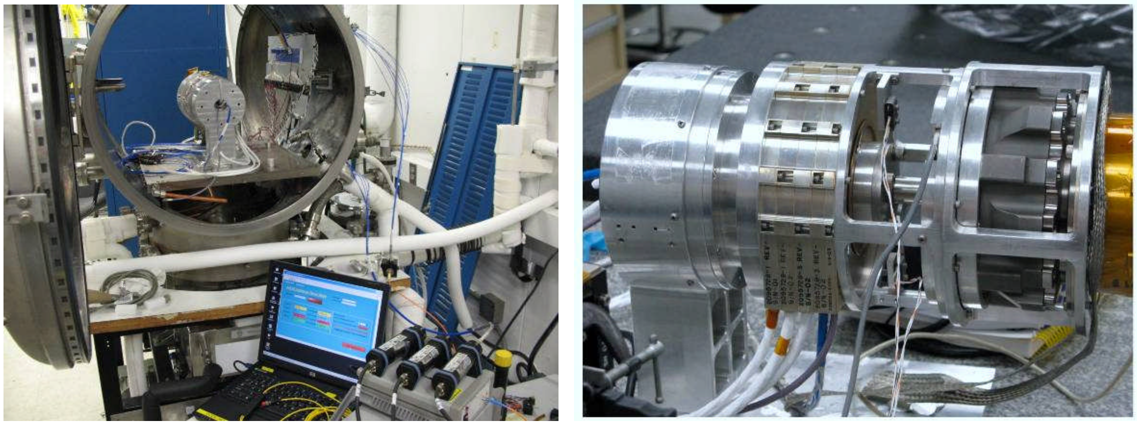

Figure 2: a) Experimental Configuration for Gimbal Life Test with Optical Fiber Bundle, b) side view of the cable wraps on the gimbal.

The gimbal life test was conducted between the thermal range of +7°C to +37°C, with 2 hours duration for ramping between thermal extremes and 78 hour dwells at the extremes. In each case 2333 mechanical cycles were conducted on the gimbals starting at room temperature and then cycling from hot to cold until the total mechanical cycles reached 14000 total. Although there were several equipment malfunction interruptions of the testing systems, the bundle performed with nominal stability. Figure 3 shows Graph 1 of the bundle under test.

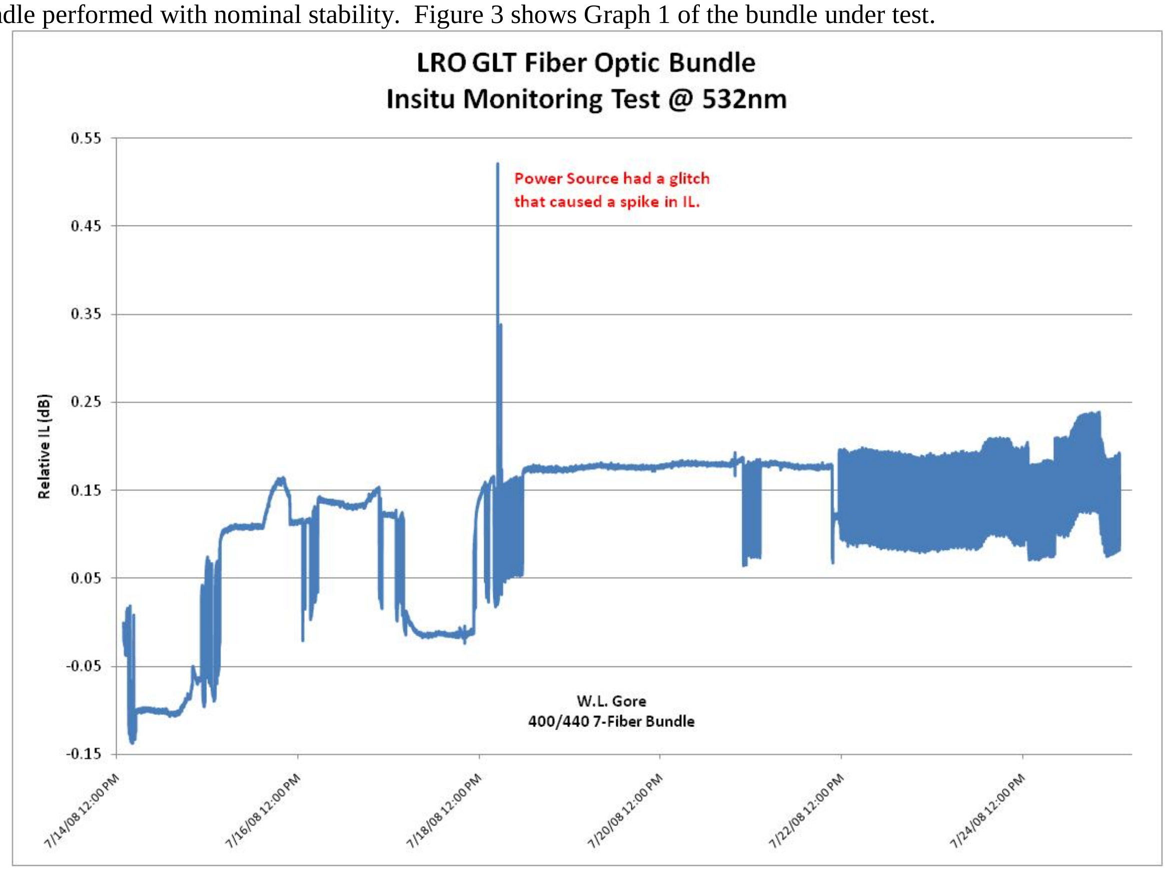

Figure 3; Graph 1 of the In-situ Insertion Loss for the Laser Ranging Bundle During the LRO Gimbal Lifetest.

Graph 1 of the testing is included here only for example purposes only. There remains a second graph of active data that shows similar results for performance tracking the cable under test. Post testing, the overall change in insertion loss for the bundle at 532 nm was less than 3% or .14 dB. The bundle performed better than system level allocations had predicted. The system level allocation for change in insertion loss per life of the mission was set for 0.3 dB based on the engineering model test results of the previous test prior to redesign.

2.2 The Mars Science Laboratory

For the Mars Science Laboratory Chem Cam instrument, the photonics group provided consulting on design, performed development and manufactured the Chem Cam flight optical assemblies for the lead engineers at NASA Jet Propulsion Laboratory in Pasadena California. Similar to the Laser Ranging application on LRO, the assemblies would be used to transmit light from the camera receiver optics while routed across gimbals and a boom to the processing optics. Again, this would be accomplished with Diamond AVIM connectors, W.L. Gore Flexlite cable and Polymicro Technologies optical fiber.

The thermal requirements were -135°C to +70°C for survival during the mission, +110°C for a few hours prior to launch and -80°C to +50°C for operation. The high survival thermal extreme was levied because of a decontamination bake out requirement for all hardware components to +110°C for several hours. To assure the engineering models would be appropriate for flight, radiation testing was conducted on the first design. When the design changed, the new fiber selection was made based on previous mission data to acquire a candidate that would perform as well as the first design candidate.

Some of the flight models from the flight lot were tested for vibration and thermal cycling to the operational thermal limits for 30 thermal cycles. The radiation requirement was 10 Krad total dose operational and 20 Krad total dose for margin or survival.

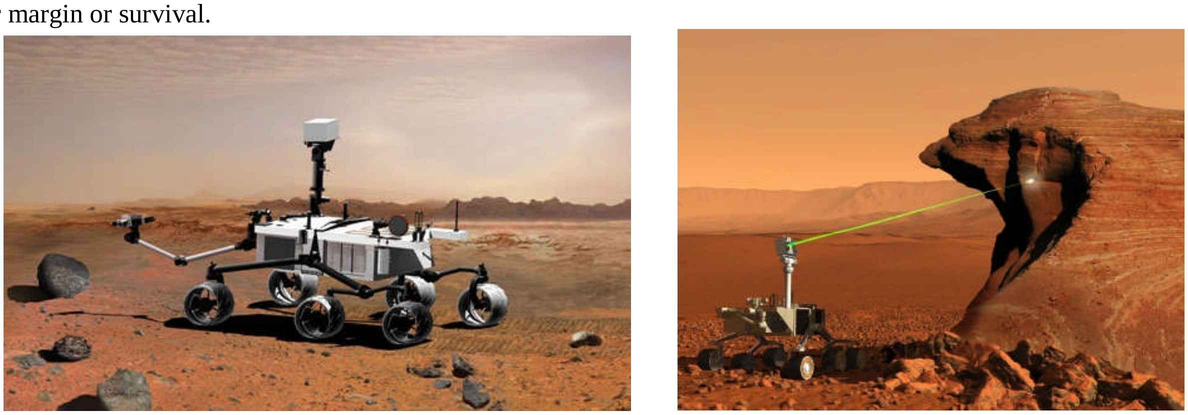

Figure 4: Artist rendition of the a) Mars Science Lab, b) Chem Cam performing analysis on rock formation

During development of the engineering models, the design utilized a 0.12 numerical aperture multimode optical fiber with a 300/330 micron diameter by Nufern. In addition, the first cable designs were produced to accommodate an array of such fibers so a larger cable was built with a 2.8 mm outer diameter. As it was determined that an array similar to the one used by the Laser Ranging project would not be appropriate for image focusing reasons, a single fiber was placed into the large cable. The prototypes were too unstable for the motion requirement and were not adopted for the flight. The fiber inside the jacketed cable and outside the cable was providing too much motion instability for usage in the final design.

2.2.1 Radiation Characterization

Since most testing schedules and flight development paths occur simultaneously, the first engineering model of W.L. Gore (Peek Tubing) cable with part number FON1442 and Nufern FUD3731, 0.12 NA, 300330 micron diameter optical fiber, was characterized for radiation performance. For gamma exposure, 10 meter samples were each exposed to 17.9 rad/min with one sample at +25°C and the other at -100°C. The monitoring wavelength range was 300 to 400 nanometers using a Xenon arc lamp and filter and all source transients were removed from the final data.

Figure 5 represents the graphical data of the fiber as it increased in insertion loss during total dose exposure. The test was conducted for as long as possible for the purpose of running a thermal model over a constant dose rate. The performance was so similar, we concluded that even at a dose rate of 17.9 rad/min and a worst case temperature of -100°C the overall expected radiation induced attenuation was less than 0.05 dB/m for 20 Krad and 0.15 dB/m for up to 130 Krad.

When the flight assemblies were designed, a suitable fiber had to be chosen to match the performance of the previous design and to have a 0.22 numerical aperture at the appropriate visible wavelength range. The Polymicro FVA300330500 acrylate coated fiber was chosen to be upjacketed into W.L. Gore Flexlite cabling part number FON1482.

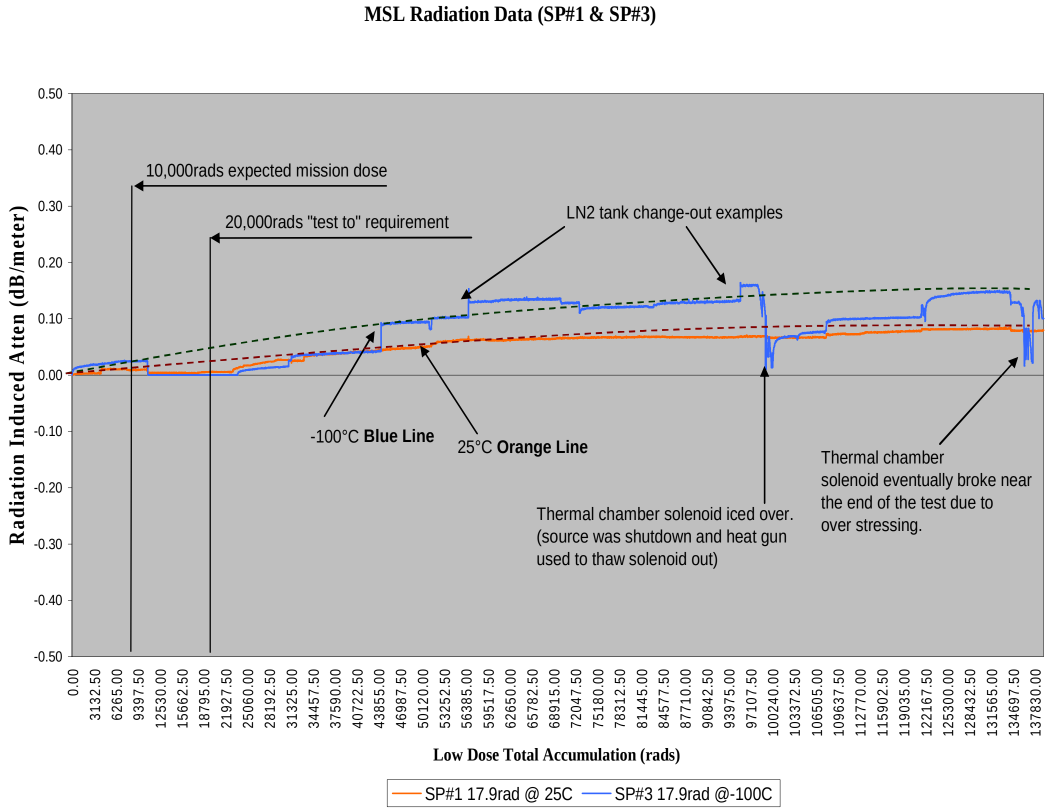

Figure 5: Radiation Data for the Nufern FUD3137 300/330, NA = 0.12 Optical Fiber

When comparing testing conducted during the development of LRO, it was extrapolated that both the Nufern FUD3137 and the FVA series fiber by Polymicro would perform nearly the same under similar conditions of wavelength, temperature, total dose and dose rate for the worst case condition.

2.3 The Express Logistics Carrier on International Space Station

The Express Logistics Carrier or ELC is meant to provide “smart” warehouse space pallets to the crew and operations of the International Space Station. As all providers to the International Space Station know, working to stringent requirements is a challenge. Coordination across government agencies and contractor entities creates even more intricacy with communications and negotiations of environmental and hardware parameters. The ELC is designed to accommodate cargo and experiments across the distance of the pallet and therefore requires a geometry of wire harnessing to match. Any experiment or module that attaches to the ELC must be compliant in speaking to the ISS High Rate Data Link (HRDL) optical fiber communications bus. Several assemblies together make up the harnessing suite of communications links on ELC. Most of the optical fiber communications links are included with other electrical harnessing therefore complicating the matter of integration. This is very common for space station hardware. Because of the inclusion of both electrical and optical fiber assemblies into a common harness, integration and handling were the highest risk to the hardware.

2.3.1 The Harnessing Design for ELC

The Flight Control Unit (FCU) or “brains” of the pallet include optical fiber transceivers built by Space Photonics and supported in screening and optical fiber assemblies by the Parts Packaging and Assembly Technologies Office of which the Photonics Group is a subset. The Photonics Group manufactured all optical fiber assemblies for the pallets and the transceivers. The FCU transceiver assemblies include a Nufern graded index 100/140/172 optical fiber part number FUD2940 in a W.L. Gore Flexlite configuration FON1435 terminated with a Diamond AVIM space flight connector. As always with the AVIM space flight connector, the hytrel boots require a 24 hour vacuum bake out at 140°C prior to termination on to flight hardware.

Figure 6 illustrates the modular plan for International Space Station with four ELC modules integrated to different locations. Figure 7 illustrates the electrical/optical fiber harness flow for each ELC module (pallet).

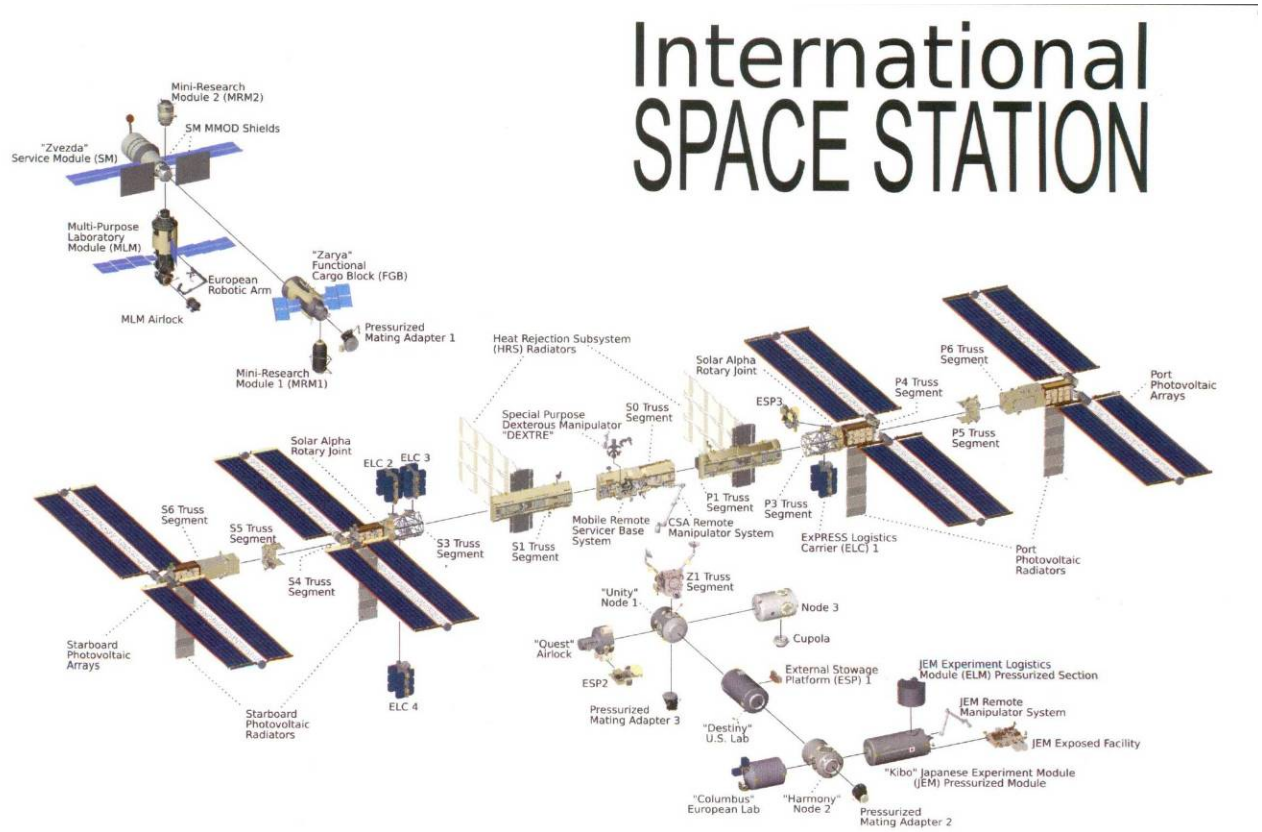

Figure 6: International Space Station Modular Plan View, 4 ELC modules pictured with Station.

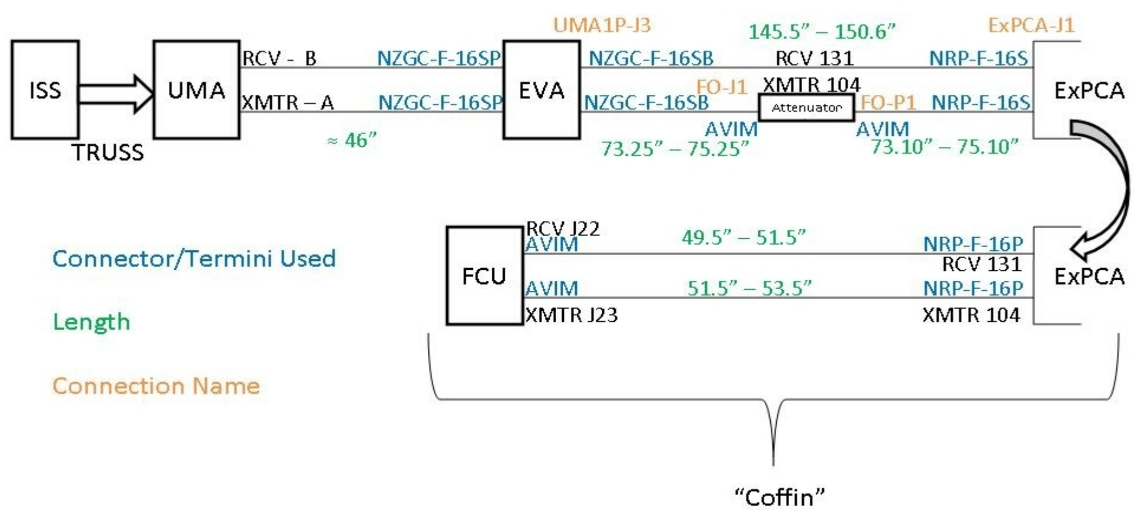

Figure 7: Express Logistics Carrier Harness Flow Map

Due the number of assemblies and the complexity of the integration, the subsystems are integrated in stages. The UMA assemblies arrived as supplied by Johnson Space Center with re-termination requirements allowed to shorten the length of the optical fiber assembly. The UMA assembly is meant to provide protection for the Space Station Interconnection for Extra-Vehicular Activity (EVA) connections (external interconnection). No thermal workmanship or preconditioning procedures could be conducted on the UMA. In Figure 7 the ISS part numbers are listed for the ELC harnessing assemblies. Between the FCU and the ExPCA, hybrid assemblies were built with the standard flight Diamond AVIM on the FCU side and the Space Station pin termini on the ExPCA side. Also on the transmit assembly from the EVA to the ExPCA an attenuator was required. To accommodate this, Diamond AVIM adapters were modified to provide a suite of variable attention in the final implementation. The design was developed by the Photonics Group. The addition of an AVIM based attenuator also required that the transmit assemblies from the ExPCA to the EVA be hybrid assemblies with ISS termini on one side and standard flight Diamond AVIM on the others. All assemblies were preconditioned when possible, inspected and built in the photonics group clean room facility.

2.3.2 The Space Flight Qualified Space Station Optical Fiber Cable.

All of the assemblies excluding those on the inside of the Flight Control Unit System box were fabricated with ISS store stock optical fiber cable. This of course begs the question "Is this the same cable that could potentially have the rocket engine defects found inherent to the cable design, during the 1999-2000 failure analysis study?" The answer to that question is "yes".[9] Per the ISS failure analysis report, the failure was based on the physics of the construction as well as an ESD sensitivity due to the carbon layer hermetically sheathing the outermost surface of the silica optical fiber beneath the polyimide coating. The failure mode was known to be time dependent. The small holes in the carbon coating that were either generated by insufficient application or by an ESD effect could allow trapped hydrofluoric acid to etch pits into the silica glass. The hydrofluoric acid was generated from a combination of water from hygroscopic polyimide and the fluorine generated inside the inner jacket layer during extrusion. Therefore over time the small traces of acid could etch slowly away at the silica glass based on the trapped geometry of the construction.

A screening process was outlined in the 2000 report [9] to screen 100% of all cable being used in the future. The method required 1st launching 532 nm light in a dark room; 2nd mechanical stressing of the fiber inside of the cable through use of small pulleys and; 3rd a follow up analysis of the fiber with inspection techniques such as the transmission and inspection of 532 nm light in the first step. The Photonics Group built the screening pulley system and screened a spool of cable that was sent by Johnson Space Center for purposes of validating the remaining Boeing cable stock. Although the cable screened fine, the failure was still known to be inconsistent even in a single run of cable which is why the screening method is required for 100% of the product used. Based on lack of findings and lack of sufficient evidence that the supplied cable possessed defects that would eventually result in loss of transmission at the current time, ISS chose to not allow the flight cables to be screened via the pulley for the remaining cable that would be used for the flight build. The reason being that the screening method required a dynamic violation of the ISS minimum bend radius specification. Therefore the Boeing/Johnson supplied optical fiber cable (now no longer manufactured in industry for the International Space Station) was used for all assemblies on ELC and was not screened past the 1st step of the screening method.

Although the cable used for the ELC mission was said to have been screened by the Boeing Company in support of Johnson Space Center ISS activities, no documentation was provided. The ISS program was willing to accept the risk for the cable remaining functional for the ELC mission duration. At present, it is not evident that this cable possesses the defects and two pallets have been successfully integrated for delivery to Space Station.

2.3.3 The Express Logistics Carrier Integration Activities

As with much of the modules that formulate the International Space Station, a great deal of effort is required to meet all ISS requirements with the highest attainable quality assurance. All assemblies built by the Photonics Group were built with current best practices for space flight terminations based on 15 years of lessons learned, with thermally preconditioned parts, in a 10,000 ppm class clean room facility at NASA Goddard Space Flight Center. All flight and ground support equipment assemblies were treated with NASA GSFC flight standards (that are viewed as excessive as compared to other flight program requirements) for handling, cleanliness, inspection, and post termination thermal cycling workmanship testing.

Figure 8: a) ELC pallet held above far above ground in integration facility, b) team integrating optical assemblies, c) inspection of optical fiber end face termini prior to integration on the ELC deck.

The tests are followed with insertion loss testing and another inspection for quality assurance at 200X magnification. The visual inspections include end face geometry interferometry to assure compliance to ISS optical fiber assembly specifications. Throughout all handling of the optical fiber assemblies during building and integration, ESD precautions and procedures were conducted.

Some of the integration of the assemblies prior to decontamination bake-out occurred at Orbital Sciences Corporation integration facilities where a majority of the electrical harnessing was built and validated. The other integration activities occurred at either GSFC or NASA Kennedy Space Center International Space Station Processing Facility operated by Boeing Corporation in Cape Canaveral Florida.
Figure 8 shows three views of integration activities. Figure 8a shows the ELC truss pallet prior to integration of the harnessing assemblies. In Figure 8b a team including the Photonics Group members and another ELC electrical technician work out anomalies during integration of ELC Pallet Deck 2, days prior to its shipment to Kennedy Space Center (KSC). Sockets were not seating properly into the ExPCA connectors and required removal. The flight from GSFC to KSC for the hardware was non-negotiable and the pallet was shipped minus these assemblies.

Figure 9a) and b): Photonics group team works at integration on ELC Deck 2 @ KSC ISS processing facility, c) inside view of assemblies out of the back end of an ExPCA connector body.

Once ELC Deck 2 arrived at Kennedy Space Center, a small team including Photonics Group members as well as ELC Harness lead and technicians completed the integration of several assemblies across the deck from the ExPCA side to the EVA (shown in Figure 7). Figure 9 shows views from the integration at KSC where delicate operations of inspection and integration were conducted on the deck while elevated over 6 meters above ground at the ISS Processing Facility near Cape Canaveral.
The schedule demands caused us to re-evaluate the integration protocols to allow for integration of the optical fiber hardware sooner in the process. This of course meant more guidance to the electrical contractor for handling the assemblies during bake-out. Other changes were made to the ground wiring such that the back shells could be adequately removed. This would therefore remove the obstacle of space constraints on the heavily occupied back shells and properly accommodate room for the optical fiber assembly insertion tools. Integration is expected to continue until the end of 2009 when all five modules should be complete.

2.4 Optical Simulator Assemblies for the James Webb Space Telescope

To functionally test the Integrated Science Instrument Module on James Webb Space Telescope (JWST), the Optical Telescope Element Simulator is being built to test the performance of the four instruments on JWST. The conditions of the test require a cryogenic environment and optically coupled light into pin holes and other fixturing over a wide spectral range of 600 nm to 5600 nm. The difficulty of cryogenic cooling and operation of optical fiber is not the material integrity of the optical fiber itself typically, it is the fixturing method used to hold the fiber in static alignment. Diamond FC and AVIM ferrules were evaluated for their performance and terminated with some standard doped and heavily doped fiber under cryogenic exposure for mechanical integrity. Three optical fiber types were tested in terminated fashion into the Diamond FC connector with ceramic shell and titanium insert using typical termination procedures. The fiber types were 1) FiberCore's singlemode versions SM600 & SM900, 2) Infrared Fiber Systems ZBLAN doped 200 micron core and 3) CorActive AsSe 30 micron core optical fibers. Both the ZBLAN and AsSe required nonstandard polishing and epoxy processes to reduce the micro-crack stresses on the fiber end faces. The final design for the AsSe is still incomplete and should be solved by reduction of the bond line thickness.

2.4.1 Cryogenic Testing on Optical Fiber Assemblies

The candidate optical fibers were terminated with flight procedures but without upjacketing, leaving the optical fiber coating as the outer most protection for the optic strands. The test was conducted at approximately 100 Kelvin and the assemblies were checked for insertion loss prior to and after testing. This was not an in situ test due to lack of available matching vacuum feed-throughs for the fibers under test.

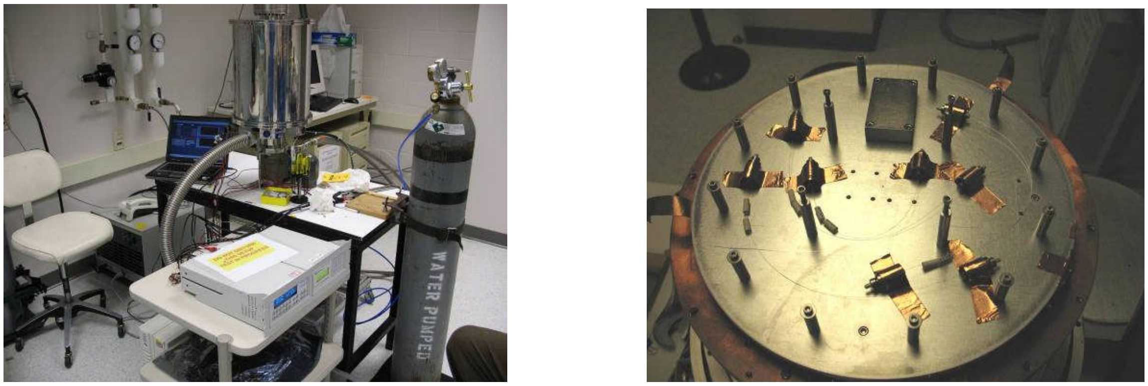

Figure 10 a) Cryogenic testing equipment set up for evaluation of optical terminations and processes, b) Top view inside of cyro chamber, optical assemblies on thermal control heat plate sitting on top of the chamber cold plate.

For the assembly data presented here, side A of all tested assemblies were Diamond AVIM ceramic shell titanium insert ferrules and on side B, Diamond FC connectors with a similar ferrule construction were terminated. Several tests have been conducted since the initial evaluation successfully. Figure 10a shows the small cryogenic chamber surrounded by the equipment set up for automatic operation and monitoring of the system for thermal compliance. Figure 10b shows the thermal plate where the fibers are mounted down at the connectors with conducting tape. The plate is thermally controlled and monitored. Figure 11 shows the cryogenic chamber thermal plate thermal monitoring data for the first test.

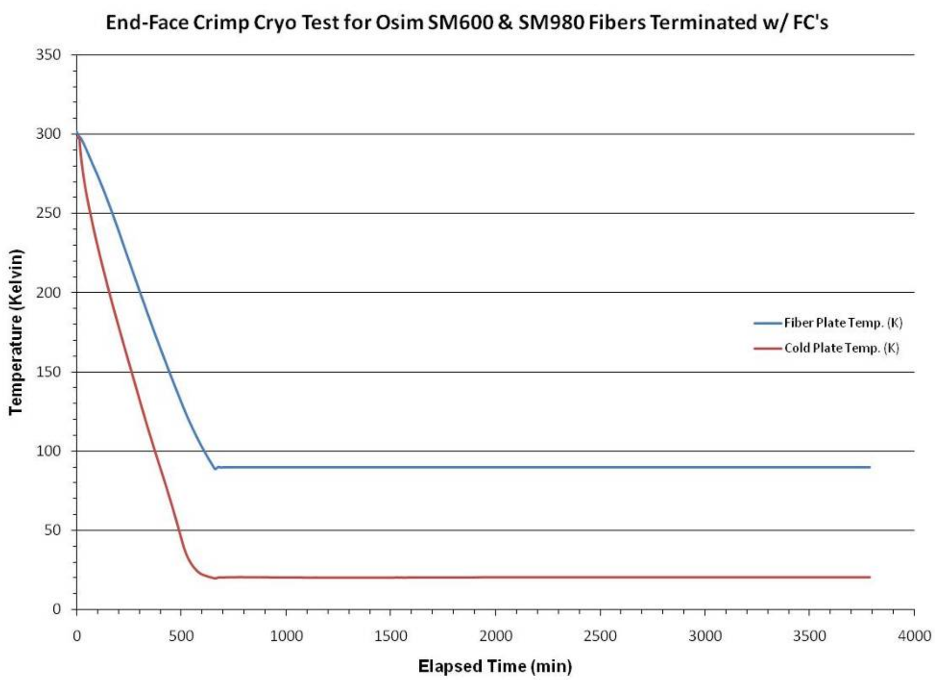

Figure 11: Cryogenic thermal data, temperature of fiber plate maintained at less than 100K, for more than 50 hours.

In Figure 11 is an example of the hardware monitoring data captured to validate that the fiber plate was compliant to the environment through out testing. This data was collected during evaluation of the terminations for the two single mode fiber types under test and in the current design.

With our current flight termination procedures and the Diamond connectors and ferrules three out of the four types of fiber have been validated to survive the cryogenic requirement and the last type will be validated shortly with a change to a smaller ferrule hole size. Integration of the entire test system is schedule to occur at Ball in Colorado before the end of the calendar year.

2.5 NASA Electronic Parts and Packaging Program Activities

Two activities are concurrently being completed for the NASA Electronic Parts and Packaging Program (NEPP) photonics task. One task is a new radiation database to update the previously published database from 2002.[10] The other task is to validate small form factor interconnects for back plane or board mount applications. The results of the radiation database are still being verified and edited and will be available later this year at the https://photonics.gsfc.nasa.gov website. The evaluation results for the Diamond DMI and "Mini AVIM" connectors will be presented here.

For the past five to ten years NASA space flight designers and the space flight manufacturers for other government agencies including the European Space Agency have requested a connector with the reliability and performance of the Diamond AVIM but with a smaller form factor for board mount applications. Since the Diamond products have been used successfully in flight for over a decade it was a natural choice to evaluate the Diamond equivalent to the AVIM for small form factor applications with flight requirements.

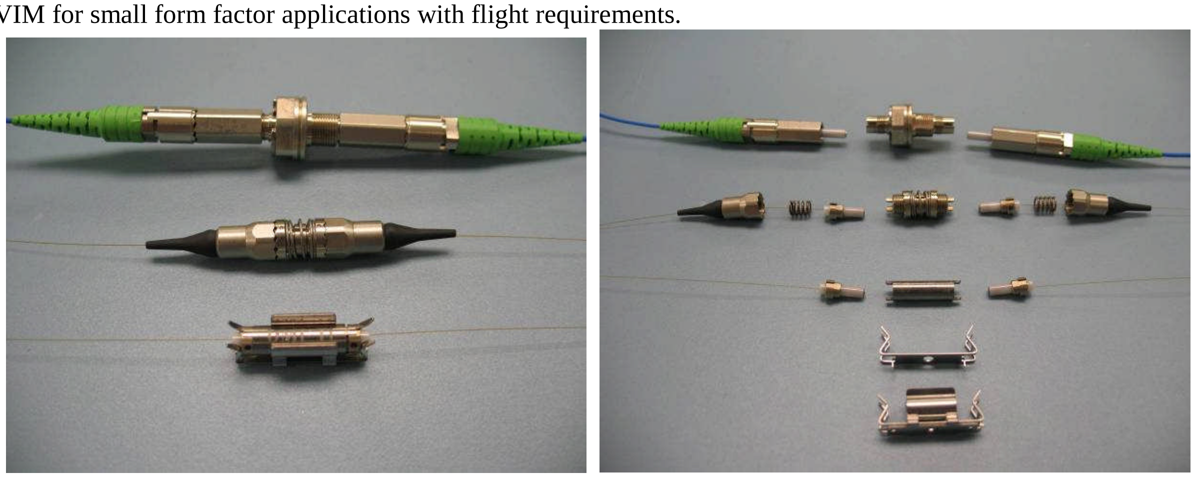

Figure 12 described from top down a) Interconnected Diamond standard AVIM on top, "Mini AVIM" for space flight, and the rugged "Mini AVIM" board mount configuration version. b) Disconnected standard AVIM with the cleanable adapter shown, Space Version "Mini AVIM", Rugged board mount configuration "Mini AVIM".

In Figure 12 the various configurations are shown from top down, the standard AVIM, the space Mini AVIM, and the board mount ruggedized Mini AVIM (DMI). The goal of this evaluation was to verify to which environments these connectors would be appropriate as compared to the performance of the flight Diamond AVIM standard. Three tests were conducted to start the evaluations; 1) pull test force for the board mount connectors, 2) thermal and then 3) random vibration.

For pull testing the unterminated connector pieces were used without termination, but for thermal and vibration testing, a mated pair set of terminated assemblies was used with in situ monitoring at a convenient wavelength. A step index FVP100120140 and FIP100120140 optical fiber by Polymicro Technologies was used for the testing due to the two wavelength ranges they provided and the ability to procure off the shelf in a timely manner. With the ability of crimping the end face of the Mini AVIM the gap between the standard ferrule size of 125 microns and the outer diameter of the fiber size could be minimized. The other reason for choosing these fibers is that they represent the family of fiber that LIDAR instruments typically use on the receiver optics where high resolution photon counting is crucial.

2.5.1 Pull Test for Retention Force on DMI Clip

Prior to conducting vibration testing, the question arose as to whether the DMI would be able to withstand a typical flight vibration environment. A retention clip pull force test was conducted to test how likely the connector would withstand the forces of typical random vibration launch conditions. To illustrate the way in which the test was conducted on the board mount Mini AVIM/DMI standard and ruggedized versions, Figure 13 shows the set up for the pull test for force to remove the cylindrical interconnect from the standard board mount retention clip.

DMI FORCE GAUGE TESTING SETUP

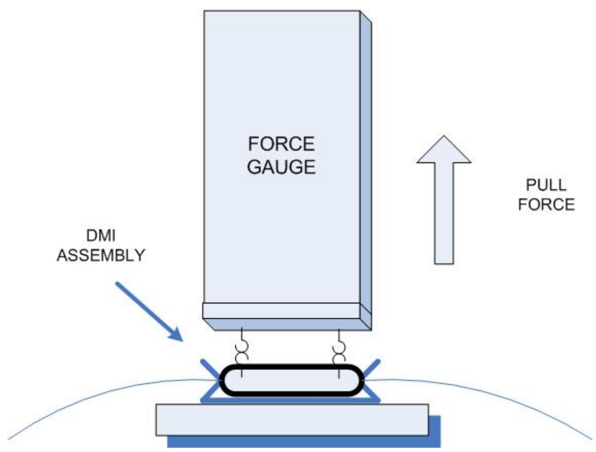

Figure 13; Pull test set up for measuring the pull force necessary to disengage the cylinder from the retention clip in the standard and rugged DMI (Mini AVIM).

For each session of 10 pulls a single connector and clip were used for two different types of materials. Table 1 summarizes the configurations and the results of averaging 10 pull force attempts per test article. A single test article consists of a new interconnection tube and retention clip.

Table 1: Summary of Retention Pull Force Results

Test Article	Type	Material	Ave. Retention Force (N)
A	Standard	Beryllium Copper	15.26
B	Standard	Beryllium Copper	17.86
C	Standard	Stainless Steel	6.20
D	Standard	Stainless Steel	6.90
E	Rugged	Beryllium Copper	45.46
F	Rugged	Beryllium Copper	43.28
G	Rugged	Stainless Steel	29.64
H	Rugged	Stainless Steel	32.24

2.5.2 Thermal Cycling Testing

Thermal cycling is always used as a validation test for termination process verification. Typically this is conducted for 10 cycles and 2 hour dwells with a somewhat benign thermal range since the objective is to test for workmanship and not for protoflight qualification. In this case, a thermal cycling test more like a qualification test was conducted of 30 cycles from -50°C to +125°C, at a ramp rate of 1°C /minute for 60 minute long dwells at the thermal extremes. The optical assemblies were connected with the three types of DMI/Mini AVIM interconnection configurations inside of the thermal chamber while in situ monitoring was conducted to watch the relative insertion loss changes over temperature shift.

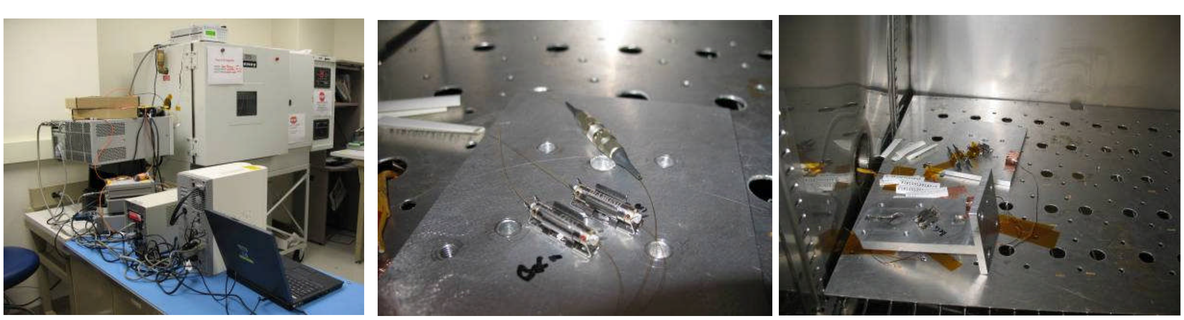

Figure 14a) Thermal cycling automated test equipment set up, b) close up of some interconnections in the thermal chamber, c) optical fiber assemblies mated into the DMI/Mini AVIMs configurations inside of the thermal chamber.

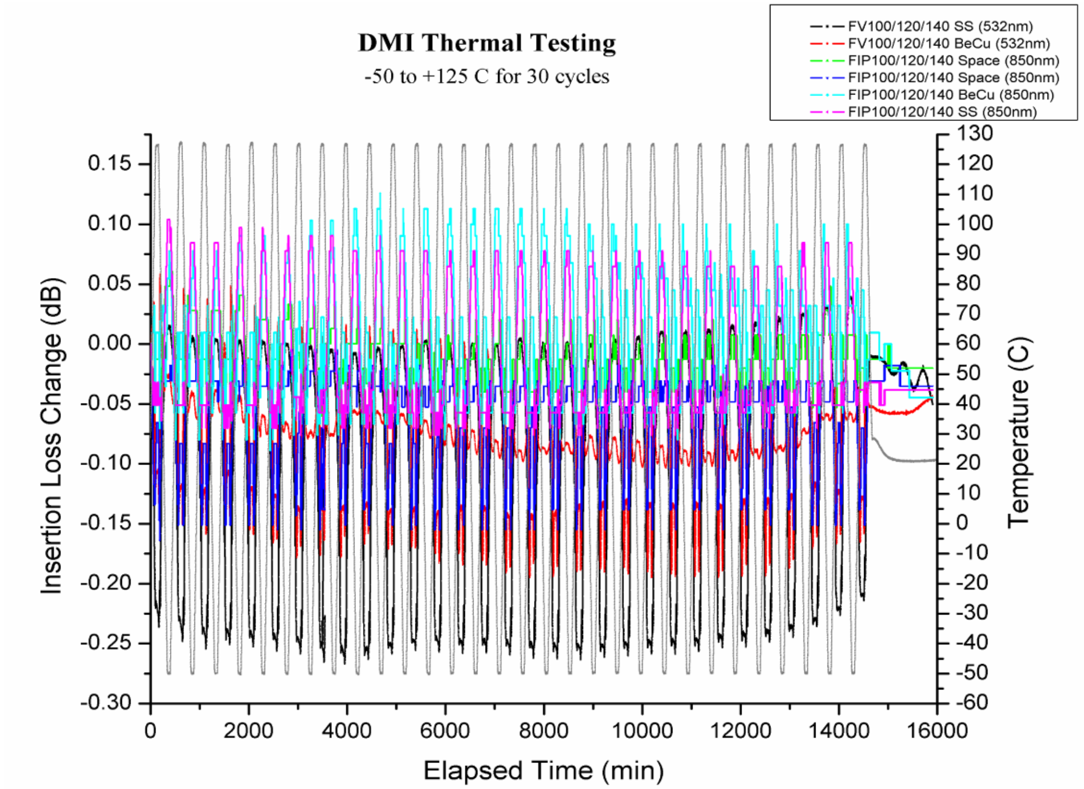

Figure 15 is the graph of the in situ data for the thermal cycling testing.

Figure 15 illustrates the performance of the assemblies during thermal cycling. The chart in Figure 15 represents the performance for all three types while interconnected in the thermal chamber: with quantity two of the space version configuration, and quantity four of the rugged version for board mount interconnection two in beryllium copper and two in stainless steel. The monitoring was conducted at 850 nm for the infrared termination or FI-series types and 532 nm for the visible fiber or the FV-series type of assemblies. The performance witnessed for all three types is typical of to that of the standard AVIMs with Flexlite configuration typically used for flight purposes.

2.5.3 Random Vibration Testing

A subset including the BeCu retention clips with the "Space Mini AVIM" from the assemblies tested in 2.5.2 were attached to the vibration shaker for random vibration testing at four different profiles that are typical to space flight or doubled in intensity at the spectrum extremes. The overall values are 9.8 grms, 14.1 grms, 20 grms, and 35 grms. The tables in Table 2 and 3 summarize the specifics of these profiles used for simulate typical launch conditions for small component qualification testing. At the subsystem small box level, Test 1 represents a typical profile where very small components are tested to the levels in Test 2 and are used for qualification on engineering models but rarely on flight articles. Something more typical of the levels in Test 1 are used for protoflight qualification where the vibration is conducted and those same articles continue to the flight subsystem final integration.

Table 2: Test 1 and 2 random vibration levels used for evaluation of the mated Mini AVIM pairs.

Test 1			Test 2	
Frequency (Hz)	Level		Frequency (Hz)	Level
20	0.013 g2/Hz		20	0.026 g2/Hz
20-50	+6 dB/octave		20-50	+6 dB/octave
50-800	0.08 g2/Hz		50-800	0.16 g2/Hz
800-2000	-6 dB/octave		800-2000	-6 dB/octave
2000	0.013 g2/Hz		2000	0.026 g2/Hz
Overall	9.8 Grms		Overall	14.1 Grms

Table 3: Test 3 and 4 random vibration levels used for evaluation of the mated Mini AVIM pairs.

Test 1			Test 2	
Frequency (Hz)	Level		Frequency (Hz)	Level
20	0.052 g2/Hz		20	0.156 g2/Hz
20-50	+6 dB/octave		20-50	+6 dB/octave
50-800	0.32 g2/Hz		50-800	0.96 g2/Hz
800-2000	-6 dB/octave		800-2000	-6 dB/octave
2000	0.052 g2/Hz		2000	0.156 g2/Hz
Overall	20.0 Grms		Overall	34.6 Grms

In Figure 17 pictures are shown of the fixturing used to hold the assemblies during testing. The profiles in Tables 2 and 3 were conducted in X, Y and Z axis configurations for three minutes / axis.

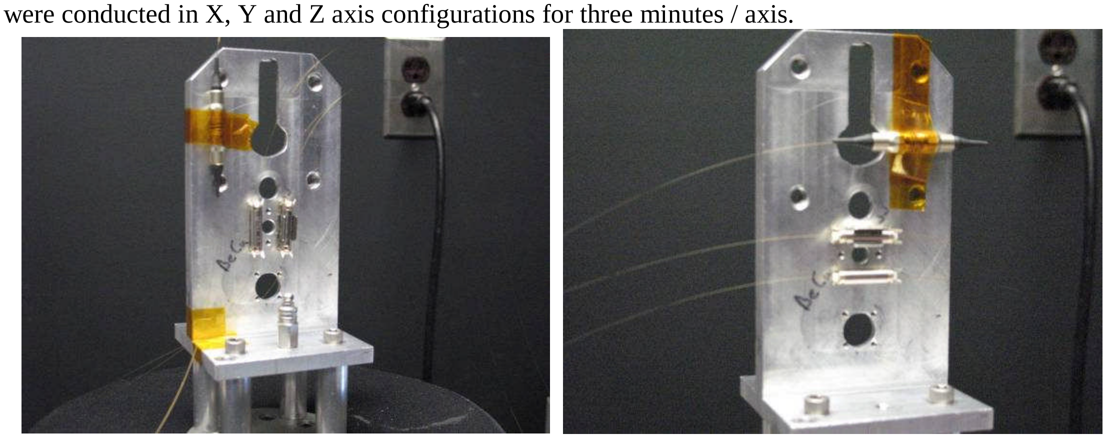

Figure 17: Fixture used and assemblies attached to the vibration shaker for the random vibration testing. The pictures show the positions for the X and Y configuration tests.

An example of the data showing some of the insertion loss performance during the harshest vibration test is in Figure 18. Figure 18 shows insitu data for the 35 grms test in the Z direction for all three assemblies under test.

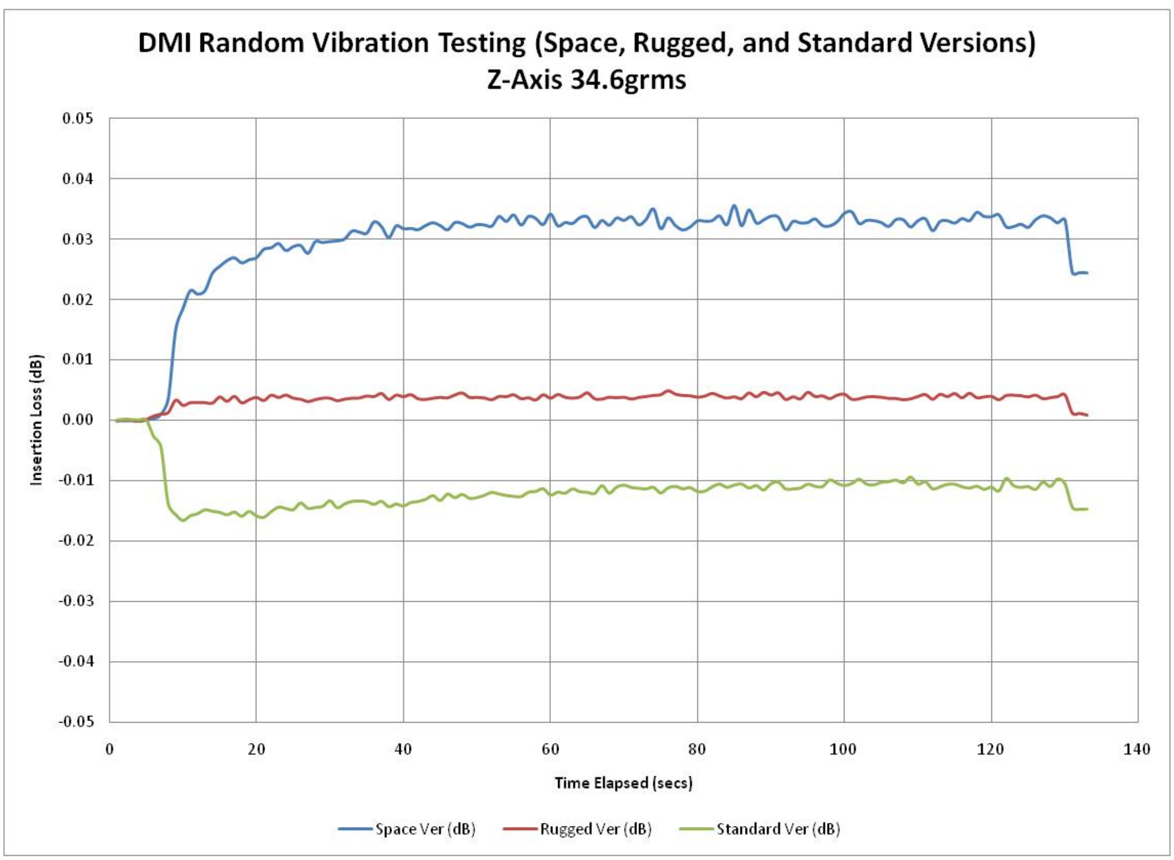

Figure 18: Example of the Mini AVIM/DMI Random Vibration Test Data.

Table 4 summarizes the results of all random vibration tests conducted. In all cases there was no indication of problems meeting typical launch requirements and throughout testing even up to 35 grms, the post testing losses were similar to the standard AVIM never reaching above 0.05 dB.

Table 4: Summary of Random Vibration Results for Insertion Loss Changes During and Post Testing.

DMI SPACE VERSION				DMI RUGGED VERSION				DMI STANDARD VERSION			
Axis	**grms Level**	**Max IL**	**Avg IL**	**Axis**	**grms Level**	**Max IL**	**Avg IL**	**Axis**	**grms Level**	**Max IL**	**Avg IL**
X	10grms	-4.8E-04	6.6E-04	X	10grms	-1.6E-02	2.9E-04	X	10grms	-1.7E-03	7.6E-05
Y	10grms	-8.3E-05	2.2E-04	Y	10grms	4.2E-04	9.8E-04	Y	10grms	-3.6E-04	2.5E-04
Z	10grms	1.2E-03	1.9E-03	Z	10grms	1.2E-05	3.4E-04	Z	10grms	1.5E-03	2.4E-03
X	14.1grms	-1.6E-03	9.4E-05	X	14.1grms	-1.3E-02	1.7E-05	X	14.1grms	-2.5E-03	1.3E-04
Y	14.1grms	6.6E-04	1.3E-03	Y	14.1grms	-2.4E-03	0.0E+00	Y	14.1grms	3.7E-04	1.2E-03
Z	14.1grms	-3.1E-02	1.4E-03	Z	14.1grms	-2.3E-03	1.8E-04	Z	14.1grms	-4.1E-03	8.0E-05
X	20grms	-1.1E-02	0.0E+00	X	20grms	-9.9E-03	0.0E+00	X	20grms	8.6E-02	1.0E-01
Y	20grms	-1.1E-02	2.1E-03	Y	20grms	-5.2E-03	2.3E-04	Y	20grms	-8.5E-03	7.4E-05
Z	20grms	-2.0E-02	3.5E-04	Z	20grms	1.2E-03	4.7E-03	Z	20grms	3.2E-03	6.8E-03
X	34.6grms	6.5E-03	1.1E-02	X	34.6grms	4.1E-03	7.6E-03	X	34.6grms	2.7E-03	6.8E-03
Y	34.6grms	2.4E-03	6.3E-03	Y	34.6grms	6.7E-03	1.0E-02	Y	34.6grms	-5.9E-04	6.0E-03
Z	34.6grms	3.0E-02	3.6E-02	Z	34.6grms	3.6E-03	4.9E-03	Z	34.6grms	-1.2E-02	1.4E-04

The evaluation is still underway and based on the results gathered here, no thermal induced insertion loss changes greater than 0.25 dB were registered and the performance of the Diamond mini AVIM/DMI connectors performed nominally during vibration testing. All of the evaluation data proved that these configurations thus far perform similar to that of the standard AVIM connector. A full report of all data collected will be available later this year on our photonics.gsfc.nasa.gov website and on the nepp.nasa.gov website.

REFERENCES

[1] http://nepp.nasa.gov

[2] M. N. Ott, "Validation of Commercial Fiber Optic Components for Aerospace Environments" SPIE Conference on Smart Structures and Materials, Smart Sensor Technology and Measurement Systems, Vol. 5758, March 2005. http://misspiggy.gsfc.nasa.gov/photonics.

[3] M. Ott, R. Switzer, R. Chuska, F. LaRocca, W. J. Thomes, L. Day, S. Macmurphy, "The Optical Fiber Array Bundle Assemblies for the NASA Lunar Reconnaissance Orbiter, Evaluation Lessons Learned for Flight Implementation," Invited paper at the International Conference on Space Optics, Fiber/Free Space Optics, (ICSO) Toulouse France, October 2008.

[4] M. Ott, R. Switzer, R. Chuska, F. LaRocca, W. J. Thomes Jr., S. Macmurphy, "Development, Qualification and Integration of the Optical Fiber Array Assemblies for the Lunar Reconnaissance Orbiter," SPIE Optics and Photonics Conference, Nanoscience and Engineering, Nanophotonics and Macrophotonics for Space Environments II, SPIE Vol. 7095, San Diego, California, August 2008.

[5] D. E. Smith, M. T. Zuber, X. Sun, G. A. Neumann, J. F. Cavanaugh, J. F. McGarry, T. W. Zagwodzki, "Two-Way Laser Link over Interplanetary Distance," Science Magazine, Vol. 311, January 6, 2006.

[6] X. Sun, G. A. Neumann, J. F. McGarry, T. W. Zagwodzki, J. F. Cavanaugh, J. J. Degnan, D. B. Coyle, D. R. Skillman, M. T. Zuber, D. E. Smith, "Laser Ranging between the Mercury Laser Altimeter and an Earth-based Laser Satellite Tracking Station over a 24-million-km Distance," OSA Annual Meeting, Tucson AZ, Oct. Proceedings, 2005.

[7] M. Zuber, D. Smith, R. Zellar, G. Neumann, X. Sun, R. Katz, I.Kleyner, A. Matuszeski, J. McGarry, M. Ott, L. Ramos-Izquierdo, D. Rowlands, M. Torrence, T. Zagwodzki, "The Lunar Reconnaissance Orbiter Laser Ranging Investigation," Space Science Reviews, 2009.

[8] M N. Ott, X. Jin, F. V. LaRocca, A. J. Matuszeski, R. F. Chuska, S. L. Macmurphy, "Requirements Validation Testing on the 7 Fiber Array Connector/Cable Assemblies for the Lunar Reconnaissance Orbiter (LRO)," Invited paper, SPIE Optics and Photonics Conference, Photonics Technology for Space Environments II, Vol. 6713, Aug 28, 2007.

[9] J. Plante, H. Leidecker, et al., "ISS Fiber Optic Failure Investigation Root Cause Report, Internal Report to NASA Headquarters" 2000, http://photonics.gsfc.nasa.gov/#ReliabilityandFailureAnalysis

[10] M. Ott, "Radiation Effects Data on Commercially Available Optical Fiber: Database Summary," Nuclear Science and Radiation Effects Conference, Phoenix, Arizona, NSREC 2002, Data Workshop Proceedings.

ACKNOWLEDGEMENTS

This paper is dedicated to the late Terry J. King, a very highly regarded NASA GSFC parts electrical engineer and long time trusted colleague and friend.

The authors would like to thank our customers for the hardware discussed. For LRO program managers Craig Tooley and Cathy Peddie; for Mars Science Lab, System Manager and Lead Engineering, Edward Miller and Chris Lindensmith; for Express Logistics Carrier Program Manager Kevin Carmack; for JWST OSIM Lead Engineer Brad Greeley and Instrument Manager Thai Pham; for NASA Electronic Parts and Packaging Program, Program Managers Ken LaBel and Michael Sampson. Thanks goes to Diamond Switzerland for supplying parts for evaluation and Bruce Meinhold at MEI for his constant support. Special thanks to Office administration staff, Tiffany Stone, Marcellus Proctor and Kusum Sahu.