The fiber optic system for the Advanced Topographic Laser Altimeter System (ATLAS) instrument

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ABSTRACT

The Advanced Topographic Laser Altimeter System (ATLAS) Instrument has been in integration and testing over the past 18 months in preparation for the Ice, Cloud and Land Elevation Satellite – 2 (ICESat-2) Mission, scheduled to launch in 2017. ICESat-2 is the follow on to ICESat which launched in 2003 and operated until 2009. ATLAS will measure the elevation of ice sheets, glaciers and sea ice or the "cryosphere" (as well as terrain) to provide data for assessing the earth's global climate changes. Where ICESat's instrument, the Geo-Science Laser Altimeter (GLAS) used a single beam measured with a 70 m spot on the ground and a distance between spots of 170 m, ATLAS will measure a spot size of 10 m with a spacing of 70 cm using six beams to measure terrain height changes as small as 4 mm.[1] The ATLAS pulsed transmission system consists of two lasers operating at 532 nm with transmitter optics for beam steering, a diffractive optical element that splits the signal into 6 separate beams, receivers for start pulse detection and a wavelength tracking system. The optical receiver telescope system consists of optics that focus all six beams into optical fibers that feed a filter system that transmits the signal via fiber assemblies to the detectors. Also included on the instrument is a system that calibrates the alignment of the transmitted pulses to the receiver optics for precise signal capture. The larger electro optical subsystems for transmission, calibration, and signal receive, stay aligned and transmitting sufficiently due to the optical fiber system that links them together. The robust design of the fiber optic system, consisting of a variety of multi fiber arrays and simplex assemblies with multiple fiber core sizes and types, will enable the system to maintain consistent critical alignments for the entire life of the mission. Some of the development approaches used to meet the challenging optical system requirements for ATLAS are discussed here.

1. INTRODUCTION

The ATLAS instrument includes a transmitter optics portion of the instrument and a receiver telescope portion of the instrument, both of which have subsystems that are linked together with optical fiber bundle/arrays or simplex assemblies. The transmitter laser sampling assembly subsystem is linked to the start pulse detectors with dual fiber arrays fanned out to simplex fibers at the detector side. A quad fiber array to fan out assembly is used to link a 532 nm LED source to precise locations at the receiver telescope for on board calibration measurement usage. Simplex assemblies are used to link the signals from the receiver telescope to its detector modules.[1]

All flight fiber optic assemblies whether arrays or simplex were terminated with Diamond AVIM connectors and W.L Gore FlexLite™ cabling with Polymicro Technologies (Molex) optical fiber from the step index FV series product line in various core sizes of 100, 200, 300 and 400 um diameters with numerical aperture (NA) of 0.22. The ground support assemblies to test the instrument were fabricated with FV400 for testing the receiver telescope or Nufern 460HP for testing of the instrument signal processing. The fiber system design was based on previous Goddard missions successes such as the Laser Ranging experiment on the Lunar Reconnaissance Orbiter which utilized a 7 fiber array with multiple interconnections and the 5 fiber array used on the Lunar Orbiter Laser Altimeter which utilized a 5 fiber array to fan out assembly [2-5]. For ATLAS, multiple dual array to fan out assemblies were used to monitor the transmitter and a quad array to fan out assembly for the on board calibration system. The fiber optic array/bundle assembly continues to be a common product for NASA and GSFC mission designs. In all, there were 1 simplex and 4 bundle assemblies used to link the subsystems for: start pulse timing, wavelength tracking and real time calibration measurements. Twelve fiber assemblies used for routing receiver telescope signals to the detectors (6 before and 6 after the optical filter assemblies)

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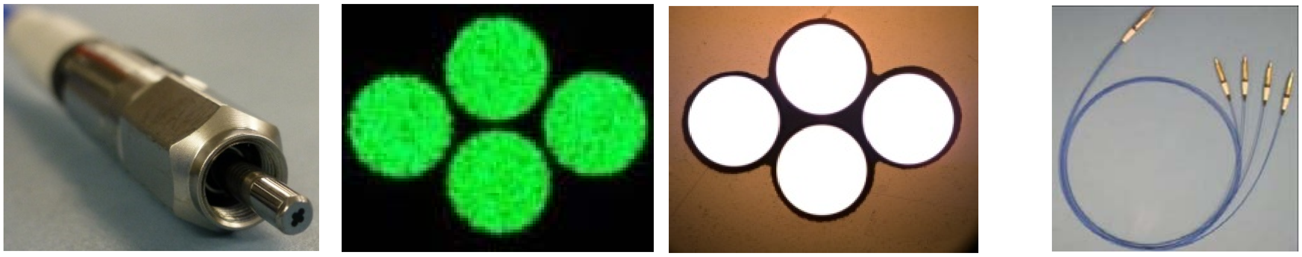
and 12 fiber assemblies (6 for testing the receiver telescope and 6 for testing the detector system) used to route ground support signals through the system for system operation performance testing measurements. Figure 1a shows a picture of a Diamond AVIM array connector with custom drilled ferrule for the quad assembly for the on board calibration system. Figure 1b and 1c show high magnification images of the quad array end faces with back lighting at 532 nm and with white light, respectively. Figure 1d is a photograph of the actual quad array to fan out engineering model assembly.



Figures 1 a-d: a) Diamond AVIM array connector, b) quad array ferrule end face back illuminated with 532 nm light, c) quad array end face back illuminated with visible light, d) quad array to fan out assembly.

Figure 2 shows a dual to fan out flight assembly with a high magnification image (pictured in center) of the dual side ferrule end face with back illumination at 532 nm.

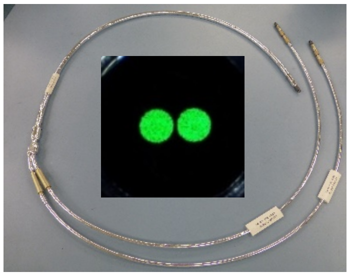


Figure 2: Dual array to fan out assembly, with back lit picture of the dual array ferrule (pictured center)

All the arrays fabricated for the ATLAS instrument required precise positioning of the fibers in the ferrule and all the arrays produced complied with those requirements. All arrays and simplex assemblies were scrutinized for performance through a number of screen tests typical of all GSFC flight fiber optic products and all of those details are not presented here. However, it is important to note that a majority of the rigor applied to the flight production of fiber optic assemblies in the way of screen testing as performed by GSFC is not commonly found in commercial industry because of the expense of the endeavor. Providing a product such as the ATLAS fiber optic system would not be profitable for a commercial business and the practices discussed here cannot be expected from a commercial product without considerable cost to both the vendor and the customer.

2. DISCUSSION

2.1 System pulse timing verification

All of the bundles and simplex assemblies for the instrument laser and receiver systems, had several key transmission pulse width and timing requirements. The fiber optic assemblies had a “do not exceed” requirement of 100 ps for links from the transmitter to the detectors. To verify this, a pulse spread measurement was necessary to determine the longest fiber link possible that still maintained requirement compliance. In order to make precise measurements, fiber lengths in 100 m increments were used for the experiment due to the narrow laser pulse required and monitoring equipment available. A Teem Photonics MNG-03E pulsed laser source was used through a diffuser and collimator and measured with a Thorlabs detector coupled to an Agilent high speed oscilloscope to capture the full wave half max (FWHM) of the transmitted signal through the optical fiber. The measured pulse spread was 14.5 ps/m maximum using FV200/220 um optical core/clad Polymicro Technologies optical fiber samples.

A second experiment was conducted for determining the timing delay as a result of transmission through the step index multimode and 532 nm single mode optical fibers on short lengths. It was determined, through repeated measurements, that a delay of 4.95 ns/m would be expected. This measurement matches theoretical calculations for light velocity in a fiber of 2 * 10^8m/s.

For measuring thermal induced timing changes in the multimode step index fibers during thermal cycling, a third transmission pulse timing test was conducted. Real time pulse measurements were recorded through a fiber assembly again using the Teem Photonics 532 nm pulsed source. A fiber assembly of 9 m in length was placed into a thermal chamber and subjected to a thermal range of 25°C to 100°C while pulse timing measurements were data logged. A measurement was recorded at increments of approximately 5 degrees C. The data is presented in the Figure 3 graph. The results showed that for an excursion of 75 degrees C, a pulse delay of 2 ps/m could be expected.

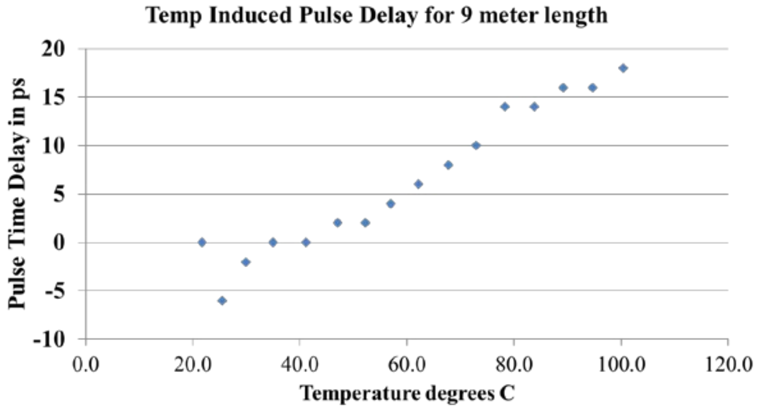


Figure 3: Thermal induced timing shift for 200/220 FV series multimode step index fiber

In order to maintain the pulse width and timing requirements for the system, the fiber links were kept as short as possible in compliance with the pulse timing requirement, but long enough to make a safe route for integration purposes.

2.2 Optimal transmission for the receiver telescope assemblies

To maximize the transmission of the receiver telescope assemblies, stringent performance requirements were levied for all optical fibers in the receiver system. The transmission requirement for each assembly was 98% without environmental effects. This meant that; lengths had to be kept as short as possible, all interconnection had to be limited to +/- 10 um radially for mechanical alignment tolerances, all fiber end faces required impeccable antireflection coatings, and the termination/packaging of the fiber assemblies to the connectors had to be optimized for thermal performance. The fiber assemblies were required to survive over a thermal range of -40°C to +70°C. Over the operational range of -20°C to +55°C, with a qualification range from -30°C to + 60°C, the optical fiber assembly thermal induced losses could not exceed 5% from nominal. Testing for compliance of the fiber, connectors (and adapters) and termination/upjacketing methods was conducted to minimize losses as a result of mechanical interconnection misalignment, thermal induced stress and radiation induced darkening effects. Table 1 includes some of the performance requirements for the optical fiber assemblies. The third and fourth columns include the performance requirement in terms of percent loss allowable, or insertion loss allowable given the environmental condition in units of dB as compared to a nominal reference measurement.

Table 1: Transmission and loss requirements for receiver fiber assembly links on ATLAS

Requirement	Transmission	Loss	Loss (dB)
Ambient nominal	> 97%	< 3%	< 0.1
Thermal Induced	> 95.5%	< 4.5%	< 0.2
Radiation Induced	> 99%	< 0.5%	< 0.05

2.3 Concentricity verification of the fiber in the ferrule

To minimize interconnection losses the mechanical tolerance for fiber interconnection was set to +/- 10 um radially for repeatability, this would include the adapter and ferrule combination. For tolerances, the mechanical adapter was allocated +/- 5 um and the fiber concentricity in the connector ferrule was allocated +/- 5 um. All of the 66 adapters on the instrument used for optical/mechanical interfaces of optics to optical fiber were manufactured by Diamond. All flanging modifications to the existing Diamond AVIM adapter were designed by ATLAS mechanical engineers from GSFC. GSFC has collected multiple mechanical/optical lessons learned from over thirty years of engineering knowledge and excellence in the form of "Gold Rules". The flanging modifications to the Diamond AVIM adapter were such that all adapters would comply with these optical/mechanical alignment requirements from GSFC and for the ATLAS instrument. Since all adapters contained the ceramic inner sleeve for centering, those adapters were expected to comply with the +/- 5 um repeatability tolerance requirement, once fully aligned with an optical system. Since by design it was assured that the adapter would meet the allocated tolerance once aligned, the fiber centering needed to be verified such that the overall optical/mechanical tolerance for repeatability would be validated.

To verify the post production concentricity of the fiber in the ferrule, high magnification measurements were necessary. The concentricity of each fiber interface used for the receiver telescope was measured using a Keyence VHX-600 video microscope with a VH-Z20R lens set for measurement of a 100x image of the fiber ferrule. The outer diameter of the fiber as positioned in the ferrule was compared to the outer diameter of a ceramic outer sleeve of the fiber ferrule. As pictured in Figure 4, concentricity measurements were made by measuring the center offset between two circles, one around the ferrule outer edge and one around the fiber edge.

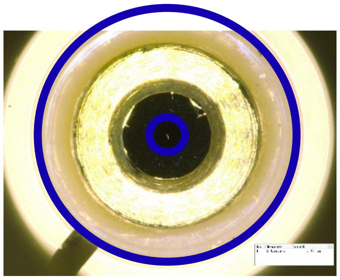


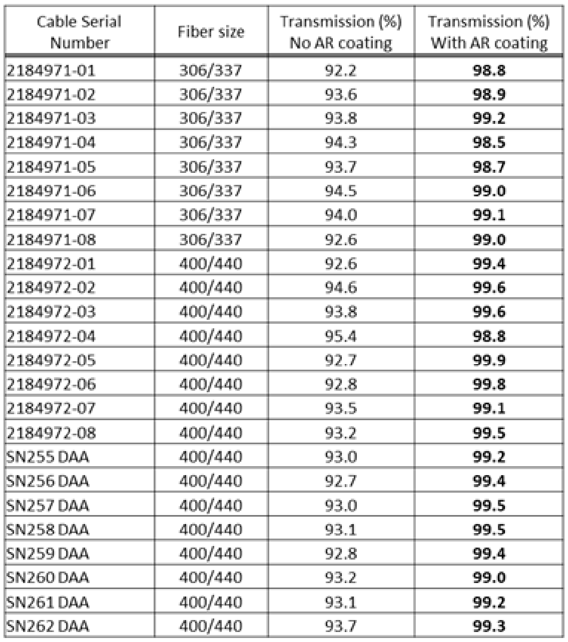
Figure 4: Fiber end face as measured with concentric circles around fiber and ceramic sleeve edges for concentricity verification of the fiber in the ferrule

The concentricity of the fiber endface in the AVIM ferrule was concluded to be at +/- 3 um based on the collected data set of more than 20 endfaces for all multimode assemblies produced for the receiver telescope.

2.4 Absolute transmission verification measurements

In order to ensure compliance with the transmission requirement in Table 1, transmission measurements were conducted before and after the anti-reflection (AR) coating application process. Testing of all receiver telescope assemblies was conducted to verify the absolute transmission of each assembly. In order to achieve this, the light launch conditions of the test set up had to match that of the actual receiver telescope. The receiver telescope injection NA for the fiber interface was .11 (f#=4.55) such that there was sufficient margin for coupling all light into the optical fiber with NA = .22. Therefore by design, the telescope was well suited to inject all of its received light into the fiber assuming the interconnection (connector and adapter together) met the mechanical repeatability requirement. To be sure that the assemblies were compliant with a better than 97% transmission requirement, each of the receiver assemblies had to be measured for absolute power transmission prior to and post anti-reflection coating application. An optical experimental set up that consisted of a 532 nm laser diode through a collimating lens a splitter (to use some of the power as a reference), followed with focal lens and aperture set for a f#=4.55, NA= .11 (1/(2f#) = NA) light injection to the fiber under test. In this way, launch conditions of the receiver telescope are used as the launch conditions to the fiber and compared to the split beam (reference). All assemblies as tested before and after application of anti-reflection coatings are in Table 2.

Table 2: Absolute transmission measurements before and after anti-reflection coating application



Cable Serial Number	Fiber size	Transmission (%) No AR coating	Transmission (%) With AR coating
2184971-01	306/337	92.2	**98.8**
2184971-02	306/337	93.6	**98.9**
2184971-03	306/337	93.8	**99.2**
2184971-04	306/337	94.3	**98.5**
2184971-05	306/337	93.7	**98.7**
2184971-06	306/337	94.5	**99.0**
2184971-07	306/337	94.0	**99.1**
2184971-08	306/337	92.6	**99.0**
2184972-01	400/440	92.6	**99.4**
2184972-02	400/440	94.6	**99.6**
2184972-03	400/440	93.8	**99.6**
2184972-04	400/440	95.4	**98.8**
2184972-05	400/440	92.7	**99.9**
2184972-06	400/440	92.8	**99.8**
2184972-07	400/440	93.5	**99.1**
2184972-08	400/440	93.2	**99.5**
SN255 DAA	400/440	93.0	**99.2**
SN256 DAA	400/440	92.7	**99.4**
SN257 DAA	400/440	93.0	**99.5**
SN258 DAA	400/440	93.1	**99.5**
SN259 DAA	400/440	92.8	**99.4**
SN260 DAA	400/440	93.2	**99.0**
SN261 DAA	400/440	93.1	**99.2**
SN262 DAA	400/440	93.7	**99.3**

The system was tested with several reference assemblies before and after flight assembly measurements were made, to verify that the experimental set up was performing in a stable manner. The data is contained in Table 2 and shows that 98% or better was achieved for the receiver fiber optic assemblies on ATLAS.

2.5 Radiation induced attenuation measurements

Although radiation induced losses for step index fiber of the FV or FI series are usually not significant for most missions with orbits such as ICESat-2 ATLAS, the fiber must be characterized for screening and information purposes. Radiation testing can be used as a screening to serve as a comparison to previous missions, even if the radiation screening is at ambient conditions. If the radiation exposure dose rate and total dose can be compared to previous data in past years, on the same fiber part type, it can be used as a lot acceptance test. In the case of ATLAS, the transmission requirements were stringent enough to require a model be generated for each of the fiber flight lots. Early in the project radiation tests were conducted very similar to the testing performed in references 2 & 6. A two dose rate test was performed to provide data to generate an extrapolation model that could be used to generate data for any dose rate and total dose combination.[2,6] Five tests were conducted for the fiber part types being considered for flight usage. Figure 5 shows an illustration of the test set up for simultaneously capturing real time radiation induced losses in the Cobalt 60 chamber at NASA Goddard Space Flight Center, on all fiber types using 19.6 rads/min and 214 rads/min dose rates.

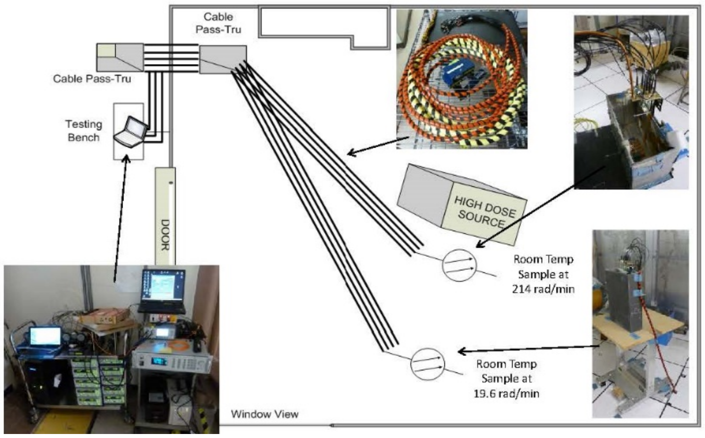


Figure 5: Radiation exposure data capture & testing set up

Five fiber candidates were tested for radiation induced performance: Polymicro Technologies; FV100120, FV200220, FV306337, FV400440 and the nLight 200220G. The data and results are presented in Figures 6 – 8 and summarized in Table 3. The four FV series fibers were tested under "dark" conditions at 532 nm and ambient room temperatures. The nLight fibers were tested using 850 nm light. The source light was monitored through-out the test and the instability of which was removed during data processing and analysis.

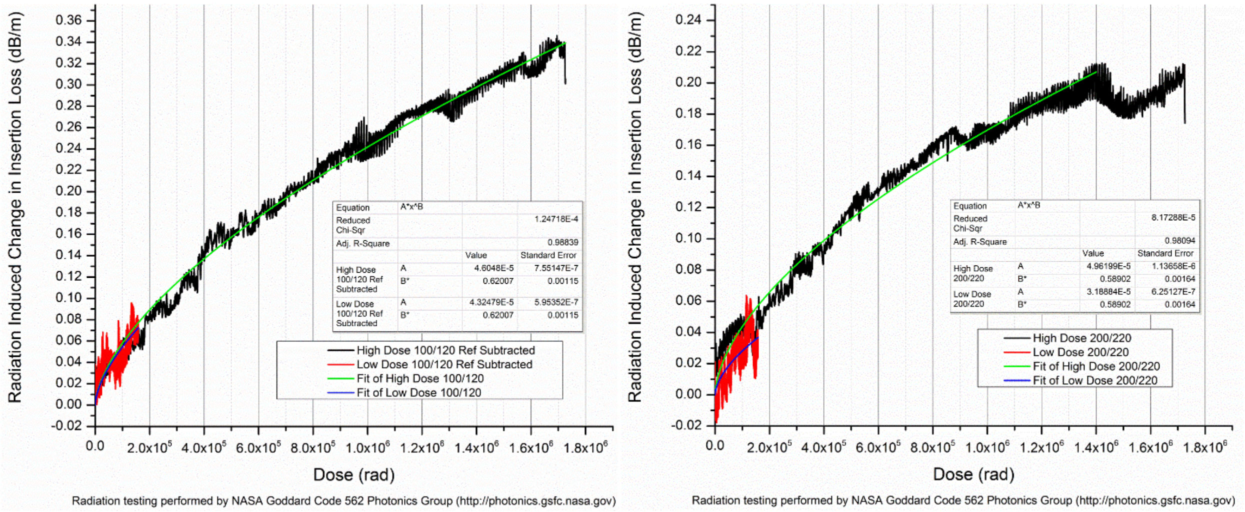


Figure 6a & 6b: Radiation induced loss data and analysis a: FV100110, b: FV200220

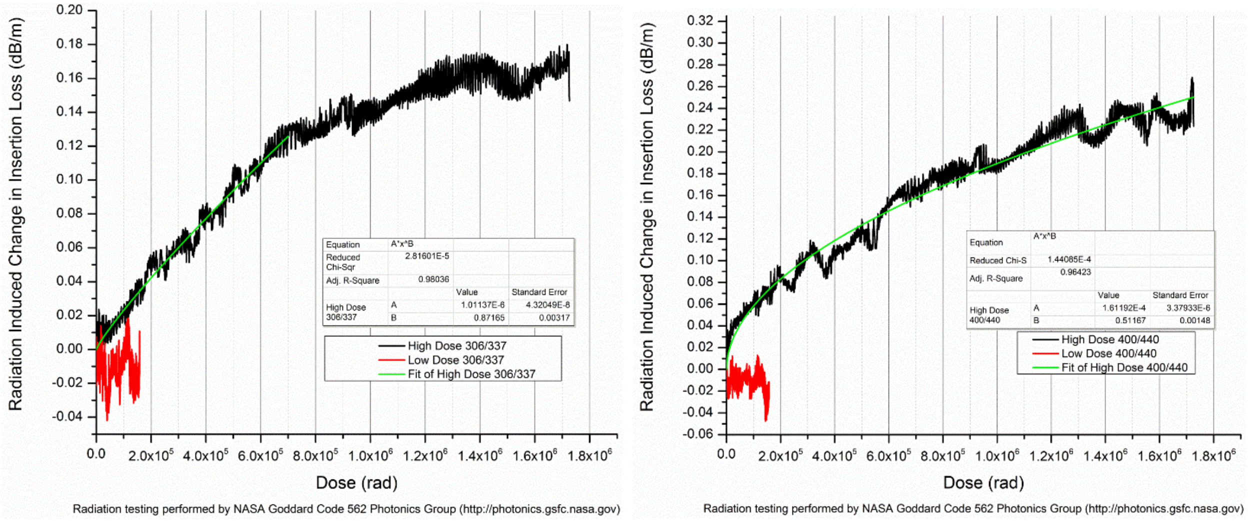


Figure 7a & 7b: Radiation induced loss data and analysis a: FV306337, b: FV400440

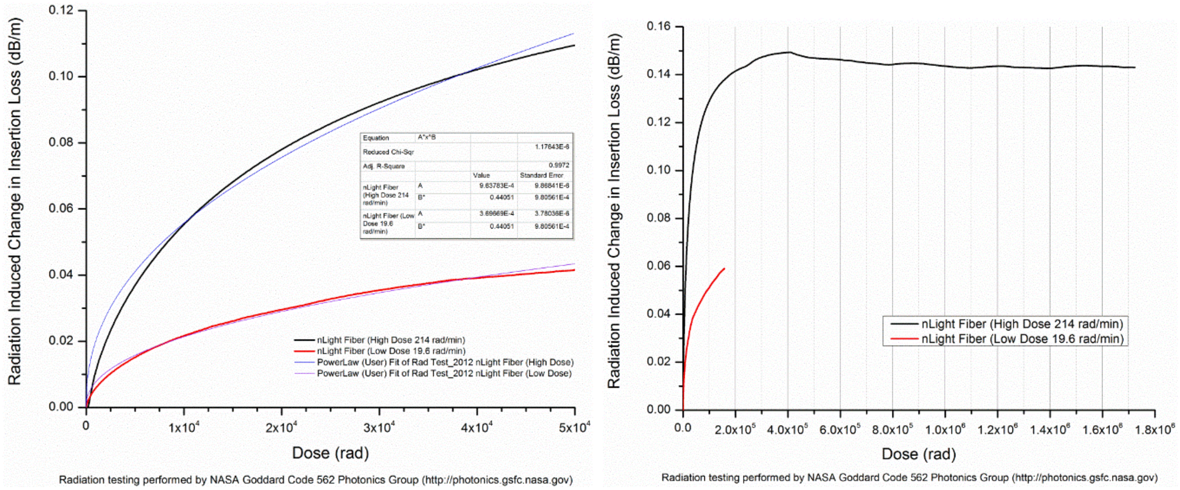
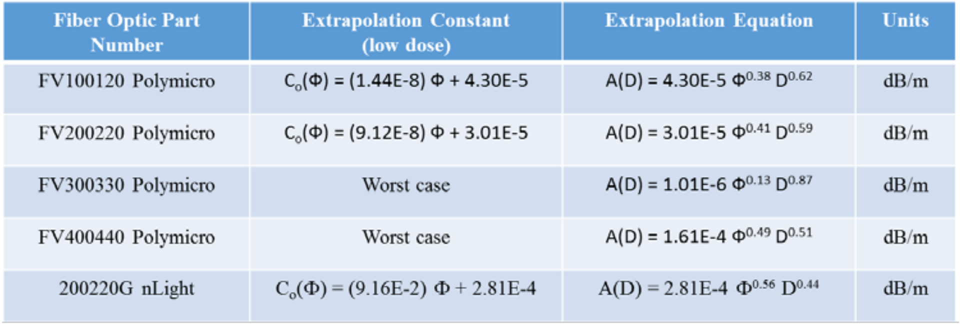


Figure 8a & 8b: Radiation induced loss data and analysis a: nLight 200220G data and model curve fit, b: nLight 200220G high dose rate data showing saturation at .14 dB/m for 214 rads/min

As is our usual test procedure for ‘dark’ radiation induced loss testing, we use power levels of less than 1 uWatt to avoid photobleaching and make measurements during radiation exposure of once per minute. Extrapolation analysis is used such that the data can be used to extrapolate to much lower dose rates. This method is not necessarily optimal for extrapolating to much higher dose rates since that is not something most NASA missions require. Table 3 summarizes the extrapolation models for each fiber type. In Table 3: Co is a constant dependent on the dose rate Φ, and A(D) is the total radiation induced attenuation as a function of total dose D, and dose rate Φ. A(D) is measured in dB/m, Φ is measured in units of rads/min and D is measured in units of rads. In the equation for A(D), Co is already a number based on the previous column calculation for low dose rate.

Table 3: Extrapolation Model Summary for Radiation Test Candidates



Fiber Optic Part Number	Extrapolation Constant (low dose)	Extrapolation Equation	Units
FV100120 Polymicro	$C_o(\Phi) = (1.44E\text{-}8)\ \Phi + 4.30E\text{-}5$	$A(D) = 4.30E\text{-}5\ \Phi^{0.38}\ D^{0.62}$	dB/m
FV200220 Polymicro	$C_o(\Phi) = (9.12E\text{-}8)\ \Phi + 3.01E\text{-}5$	$A(D) = 3.01E\text{-}5\ \Phi^{0.41}\ D^{0.59}$	dB/m
FV300330 Polymicro	Worst case	$A(D) = 1.01E\text{-}6\ \Phi^{0.13}\ D^{0.87}$	dB/m
FV400440 Polymicro	Worst case	$A(D) = 1.61E\text{-}4\ \Phi^{0.49}\ D^{0.51}$	dB/m
200220G nLight	$C_o(\Phi) = (9.16E\text{-}2)\ \Phi + 2.81E\text{-}4$	$A(D) = 2.81E\text{-}4\ \Phi^{0.56}\ D^{0.44}$	dB/m

From the data it was calculated that the radiation induced losses for the ATLAS environment are expected to be less than 0.005 dB for a 3 m long segment (less than 0.2 %), The ATLAS radiation requirement for the optical fiber system was a total dose of 8 Krads over the life mission of 1155 days. The data collected in this testing was not dissimilar from data collected for the Lunar Reconnaissance Orbiter Mission [3] for the Polymicro FV series optical fiber types.

2.6 Thermal induced attenuation verification measurements

Thermal induced effects are typically the most influential on fiber optic assembly transmission stability. Most cable assemblies have to be evaluated for thermal stability of the connector, cable, and termination into an assembly, in order to be fully characterized for a space flight mission. In many cases, qualification data by connector type or by cable type alone is insufficient for ensuring an assembly will perform well in a flight environment. This is because if the termination procedure of cable/fiber attachment to the connector is not optimized for thermal stability then it will not perform as expected or as required. The only way to ensure an assembly will perform well is to properly thermal precondition the cable itself prior to termination with a connector. In addition to proper preprocessing of the fiber cable, if sufficient mechanical isolation of the cable strain from the fiber held into the ferrule is not attained via the termination procedure, then the assembly will not perform well during thermal excursions. Our figure of merit for a flight mission with benign thermal requirements like that of ATLAS, is a transient of 0.3 dB maximum over the entire thermal range, per assembly. In a properly terminated assembly, the Diamond AVIM connector and W.L.Gore FlexLite™ combination can change by 0.25 dB during exposure to the qualification thermal range of ATLAS and therefore the thermal requirement for the receiver assemblies on ATLAS was set to 0.2 dB or 95.5% transmission for thermal induced losses over the thermal operational range. Since the quad array (4-fiber) assembly built for the on-board calibration system on ATLAS was a variation on a theme from the Lunar Orbiter Laser Altimeter (5-fiber array), thermal evaluation was necessary to prove that this new array design was viable for flight.[2]

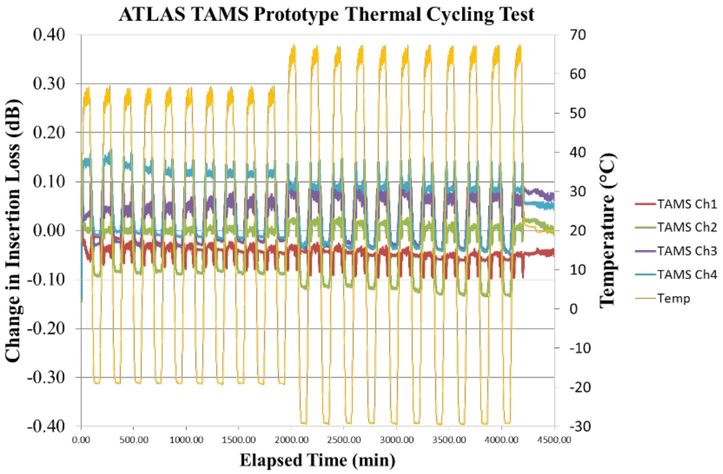


Figure 9: Thermal induced loss data for the quad array assembly prototype called “TAMS”

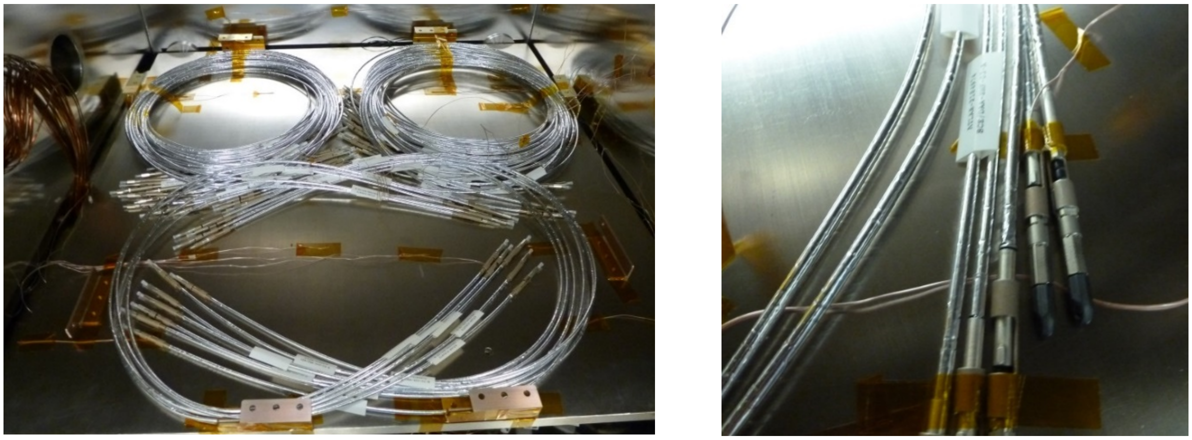
Figure 9 includes the thermal induced loss data for the 400 um core FV series fiber in FlexLite™, quad array to fan out assembly as measured real time during thermal cycling for 10 cycles from -20°C to +55°C and 10 cycles from -30°C to +65°C. The data showed thermal induced losses during cold were never higher than 0.15 dB, which is typical for single fiber assemblies not packaged into arrays. By these results, the optical fiber assembly configuration was therefore validated to be used for building engineering and flight models for the on board calibration system on ATLAS.

2.7 A Late Requirement; Conductive Coatings

During the course of the mission development and long after the flight lot had been in screening, a late electro static discharge (ESD) requirement was levied by the space craft provider for the entire instrument. This requirement was levied to eliminate all non-conducting surfaces to reduce ESD as a result of space craft charging. Since FlexLite™ is a non-conducting polymer, it was no longer acceptable as an over-jacket and would require a metal over-jacketing material to be applied prior to integration to the rest of the instrument. As a result of this requirement, an outer protective jacket had to be applied on top of the FlexLite™ on each of the assemblies. This was necessary for handling purposes since the assemblies would need to be handled in such a way as to apply a conductive tape on the surface of each assembly. The conductive tape, when applied correctly, provides a conductive surface along the length of the assembly and links each connector electrically, with the understanding that all connectors would eventually be grounded to the structure of the instrument. FlexLite™ alone is the thickness of spaghetti and cannot be handled rigorously enough to correctly apply a tight conductive tape along its entire length. In spite of the late requirement, the assemblies still had to be delivered on time and with full compliance to all performance requirements. A creative solution was necessary that would take less than two months from concept to manufacturing. An external jacket over the existing FlexLite™ fiber cable was needed and attachment method as well, to secure the jacket to the connector body.

An external jacket was selected that would comply with outgassing requirements. Once the external jacket was applied, a method for holding the jacket onto the connector without stressing the fiber during thermal excursions had to be devised. We developed a thermal slip sleeve to isolate the movement of the jacket as a result of material thermal expansion from that of the fiber optic itself. Since the initial development of the thermal slip sleeve, we have conducted 10 additional iterations of this part to manufacture it smaller, and more effective. The evaluation conducted and presented here for ATLAS was on an early version of the slip sleeve that from concept to flight termination took two months to complete. In this way we were able to maintain our instrument delivery schedule for the fiber optic system. Although the early versions of the slip sleeve did the job functionally, they were 3 inches long. Current iterations on the design are now 1 inch long and use much less material.

In order to properly evaluate how a fiber optic assembly performs over a thermal range, real-time data has to be collected while the assembly is in a changing thermal environment. Several evaluations were conducted to ensure the flight assemblies were going to perform correctly during thermal excursions. When the thermal induced losses matched that of the expected losses for a typical flight assembly with FlexLite™ attached to an AVIM connector, then the assembly was accepted for use as verified for thermal performance. The flight lot was thermal cycled for workmanship post production as is typical for all flight assemblies fabricated at GSFC. Figures 10 a & b show pictures of the assemblies in the thermal vacuum chamber before undergoing thermal workmanship testing. In these figures the flight assemblies include the thermal slip sleeve and conductive tape over a polymer jacket. The FlexLite™ cable is under the polymer jacket.

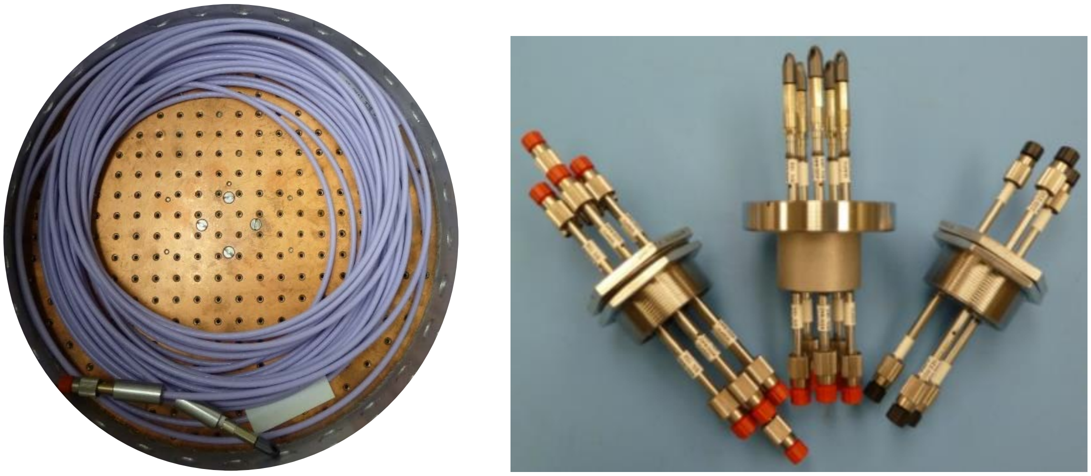


Figures 10 a & b: a) flight lot assemblies in the oven for thermal vacuum workmanship testing, b) fiber assembly ends on the TVAC oven thermal controlled plate with thermal couples attached to the assembly slip sleeves.

2.8 Ground support thermal vacuum assemblies for cryogenic temperatures

For ground support testing, 50 ft cables were required to link the fiber optic thermal vacuum feedthru's to the instrument while the instrument was enduring thermal vacuum (TVAC) testing post integration. These TVAC assemblies were expected to see temperatures as low as -115°C (considered cryogenic).

Fiber types for the ground support system included Nufern single mode fiber types at 633 nm (630HP) and at 532 nm (460HP), and two sizes of Polymicro FV series multimode fiber of 200 um and 400 um core diameters. For this ground support TVAC assembly, we designed a different upjacketing with a newer version of the thermal slip sleeve. CarlisleIT LITEflight® ND, NFO-HD, 3.8 mm outer diameter jacketing was used for building the ground support cryogenic assemblies. This cable was designed originally by the vendor as a high density cable for MTP interconnection among other fiber bundle applications. This cabling was procured without fiber inside and custom fibers were fed into the jacketing post thermal preconditioning of the jacketing material. Figure 11a shows a picture of a 50 ft hybrid FC type to AVIM type connector assembly made with LITEflight® ND cable jacketing lying on the bottom of the cryogenic plate. The cable assembly is fabricated by GSFC with Diamond FC and AVIM connectors and GSFC designed thermal slip sleeves. Figure 11b, shows a photograph of custom optical fiber thermal vacuum feedthru's as designed and manufactured for ATLAS with fibers and connectors of various sizes and types, one of which was used for cryogenic testing of the TVAC ground support assemblies.



Figures 11 a & b; a) CarlisleIT LITEflightND cable terminated with FC and AVIM connectors by GSFC, b) optical fiber TVAC feedthrus as fabricated and designed for ATLAS by NASA GSFC

To verify that the ground support hardware would survive the TVAC instrument level testing the assemblies endured testing under conditions where the cable itself was placed on the thermally controlled plate and the ends of the assemblies were mated directly to the TVAC fiber feedthrus. In this way we could simulate the actual conditions of the TVAC testing configuration, where the connectors would be at the temperature of the instrument and the cable would be at -115°C. Since the cryogenic chamber is small, each 50 ft cable with a different fiber type was tested alone. Each of the 400 um, 200 um and single mode 532 nm configurations were tested over multiple cryogenic cycles. Each cycle would range from 7 to 12 hours at -115°C and brought back to 25°C for approximately the same amount of time as the cold soaks. In actual instrument and observatory TVAC testing each cold temperature soak would be endured for days. A minimum of 4 cycles were conducted for each test candidate. The cables were montiored real time for thermal induced transmission changes while the source was monitored for the multimode fiber assemblies only (for the purpose of extracting the source drift from the data later). Figure 12 shows the experimental test set up.

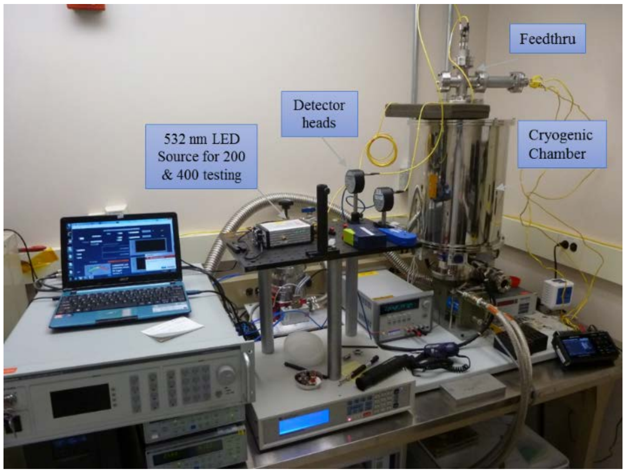


Figure 12: Experimental set up for cryogenic testing of the ATLAS ground support TVAC assemblies for usage at -115C.

Each type of fiber assembly was tested for nearly two weeks. In some cases multiple tests were conducted in order to be certain of the data and thermal couple stability. Post testing, each cable was verified for lack of damage by uncoiling the assembly completely and once again performing insertion loss measurements after uncoiling. Thermal induced losses at -115°C for the 400 um core fiber assembly configuration was 3.25 dB, for the 200 um configuration was 3.25 dB and less than 0.15 dB for the single mode configuration. The single mode test was rerun multiple times and the cable assembly endured more than 12 cycles as the test set up was checked and rechecked for stability to be sure the 0.15 dB result was indeed correct. None of the cables broke as a result of enduring the thermal testing and all were verified post testing for nominal insertion loss at ambient.

CONCLUSION

The ATLAS instrument is currently undergoing the final stages of integration and testing and since testing has begun there are no issues thus far. The instrument is scheduled to transport for observatory integration and testing in November 2016 and is scheduled for launch in 2017. The fiber optic system as integrated and verified represents a five year effort and a successful endeavor for design, development, implementation and integration of a sophisticated optical space flight instrument.

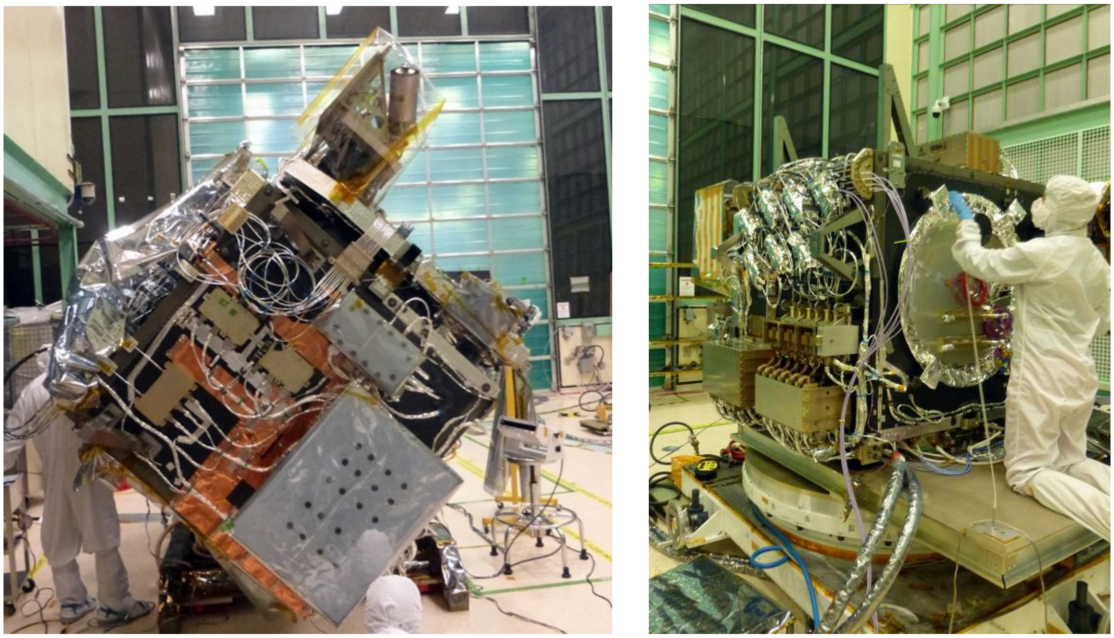


Figure 13: Integration Pictures of the ATLAS Instrument, two views of the instrument during final stages of integration at Goddard Space Flight Center

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