The Fiber Optic Subsystem Components on Express Logistics Carrier for International Space Station

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Abstract

The United States, National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC), Photonics Group in the Electrical Engineering Division of the Applied Engineering and Technology Directorate has been supporting the design, development, manufacturing and integration of the optical fiber subsystem on the Express Logistics Carrier for the International Space Station (ISS). The optical communication harnessing was manufactured, tested and integrated by the Photonics Group and the photonic transceivers were built by Space Photonics Inc, (SPI) with support from the Parts and Photonics Groups for development and screening. Some of the activities and relevant lessons learned are presented here.

Introduction

The Express Logistics Carrier (ELC) is designed to be a smart warehouse for the ISS. The Express Carrier Avionics (ExPCA) will include the Flight Control Units or “brains” of the carrier pallet that utilize, a single channel optical fiber transceiver operating at ~1310 nm for 125 Mbps operation and supplied by Space Photonics, Inc. from Fayetteville, Arkansas in the USA. The transceivers were built to comply with the High Rate Data Link (HRDL) optical communications network requirements on ISS. Five flight ELC decks will be delivered, each containing an ExPCA and the necessary harnessing required for communication to future experiments residing on ELC. Four of these decks will be remain in orbit with the ISS. The first two decks are scheduled to launch aboard the shuttle no earlier than November 2009; the third and forth no earlier than May 2010 and September 2010 respectively.

1. TRANSCEIVER

1.1 Transceiver Requirements

The ISS HRDL requires the transmitter have a signaling rate of 125 Mbps +/- 0.1%, an optical center wavelength between 1270 and 1380 nm, and a transmitted signal extinction ratio of 5% minimum; to properly interface with the HRDL network. The receiver is to have a signaling rate of 125 Mbps +/- 0.1%, an optical center wavelength between 1270 and 1380 nm, a received signal extinction ratio of 10% maximum, and a receiver bit error rate (BER) of 1.0E-9.

To meet the ISS specifications, Goddard Space Flight Center (GSFC) required the transmitter for the transceiver to be fabricated with an optical output peak wavelength between 1290 and 1330 nm typically operating at 1310 nm and an average optical output power between -7.0 and 0.0 dBm, typically operating at -4.0 dBm. The receiver is to have a BER of 1.0E-9, operate between 1250 to 1600 nm, and have an optical sensitivity of 1 to -36.2 dBm. The thermal requirement for the Flight Control Units in which the transceiver would reside was set for -20°C to +60°C.

1.2 Transceiver design and testing

Originally the transceiver was to include a light emitting diode (LED) and a photodiode hermetically packaged by Teledyne. Since these components are no longer in production (implying a long lead time) an alternative was sought. A laser diode was chosen instead of an LED since laser diodes typically have better stability and performance in harsh environments. The laser chosen for the transceiver has a maximum output power of 6 mW. The laser is operating at a power that is above what is necessary but what was required by the ISS/GSFC specifications. The ISS specification is written to accommodate any anomalies in the harnessing system currently implemented. There are assemblies in the ISS HRDL system that are suspected to be high loss due to anomalies investigated in the late 1990’s.[1] The original specification has proven to over-estimate several of the parameters once testing commenced. An attenuator was designed and implemented to compensate for over estimation of the transmission power required. (section 2).

The ISS specification of a 5% (Re=20, or 13 dB) extinction ratio limit for the transmitter could not be met with the SPI transceiver design since the component was fabricated to meet the thermal requirements and a wide dynamic range. It was suspected that the ISS Re limit was set prior to the development of detector technologies that now have sensitivity advances and to leave margin to accommodate any possibility of cracked fiber in the ISS harnessing system. Several tests were run to test the overall transmission, attenuation necessary and the extinction ratio required using a simulator for testing ISS components. To test for feasibility of a lower extinction ratio, four transceivers having extinction ratios from 5% up to 40% ((Re=2.5, 4 dB) were tested with the Automated Payload Switch (APS) in the ISS Systems Integration Laboratory (ISIL) at Johnson Space Center (JSC). The system testing took into account high losses in the ISS subsystem as a result of potentially cracked fiber and still resulted in a greater than 40% (Re=2.5, 4 dB) extinction ratio while maintaining error free operation. This convinced the team that the Re parameter could be lowered with sufficient margin. The limit was lowered to 15% (Re=6.7, 8.2 dB).

To qualify the transceiver for space flight use the following screening tests were performed:

nondestructive bond pull, temperature cycling, constant acceleration, particle impact noise detection (PIND), burn-in, gross leak seal testing, radiographic, and destructive physical analysis (DPA). Those that passed all screening tests were considered for the flight units and implemented.

2. ATTENUATOR

2.1 Attenuator Design

The attenuator was required to: have a value of 10 dB with a tolerance of +/- 0.5 dB, survive a minimum vibration level of 10 Grms, operate in a thermal range of -106°C to +85°C, and be radiation insensitive. To meet these requirements an AVIM adapter manufactured by Diamond was modified by the Photonics Group to provide an adjustable air-gap attenuation using spacer pieces of Macor.

2.1.1 Attenuator Thermal Qualification

To evaluate the attenuator for thermal compliance, two tests were performed; a cryogenic test at -180°C for 24 hours and a thermal cycling test of 100 cycles from -55°C to +85°C with 30 minute dwells at the extremes and a 5°C per minute ramp rate. Two attenuators were used in each test. A standard Diamond AVIM adapter was used as a reference.

No cracks, chips, scratches, or any other form of damage appeared on any of the fiber endfaces or attenuators tested as a result of cryogenic testing. The cryogenic test was conducted at 93 Kelvin for 24 hours. The maximum change in loss at 93 Kelvin for attenuator 1 was 0.157 dB, attenuator 2 was 0.102 dB

Thermal cycling evaluation proved that a bake-out of the Macor parts was required prior to implementation. A typical bake out of 100°C for 48 hours in a vacuum of 10^{-6} Torr was used to precondition the attenuator components.

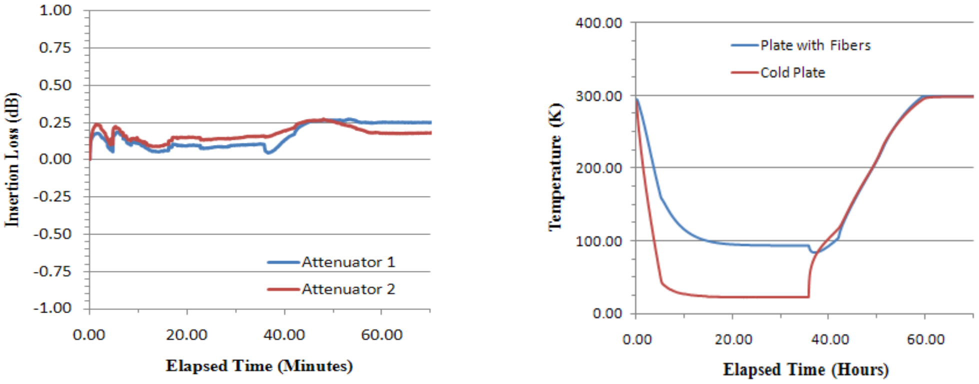


Fig. 2: a) Attenuator Cryogenic Insertion Loss Data vs Time at Cryo, b) Thermal Couple Data from Cryogenic Test.

2.1.2 Attenuator Vibration Qualification

Vibration testing was performed on two attenuators at a typical profile of 14.1 Grms and 20.0 Grms.[2] The test was conducted with in-situ monitoring at 1310nm and an accelerometer was used for vibration feedback and monitoring. A two axis test was conducted and after each axis test was completed/attenuator, the fiber endfaces and attenuator pieces were thoroughly inspected and photographed. No cracks, chips, scratches, or other damage appeared during any of the vibration testing. The results of the vibration testing showed that both attenuators maintained stability to better than 0.01 dB/axis test. The data of attenuator 1 is in Figures 3a and b.

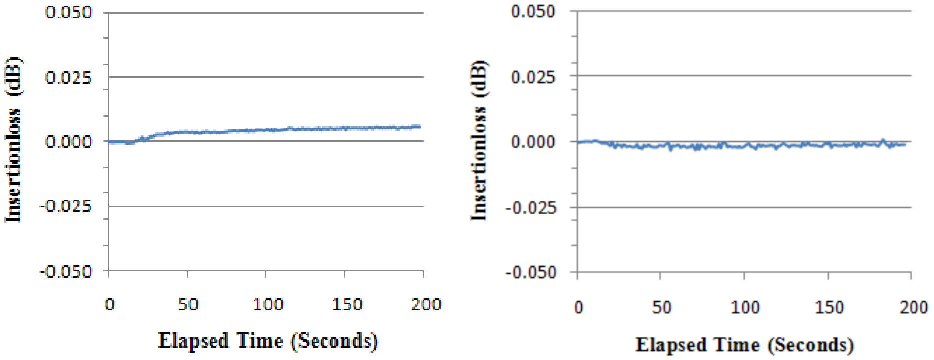


Fig. 3: a) Insertion Loss Monitoring during random vibration testing of Attenuator 1 @ 20Grms a) Horizontal Axis, b) Vertical Axis.

2.1.3 Attenuator Radiation Qualification

Radiation testing was performed at 20 Rads/min on two attenuators and a standard Diamond AVIM adapter. The test lasted for 115 hours for a total exposure dose of 2300 Rads. No damage occurred as a result.

3 HARNESSING FIBER

3.1 Harnessing Design for ELC

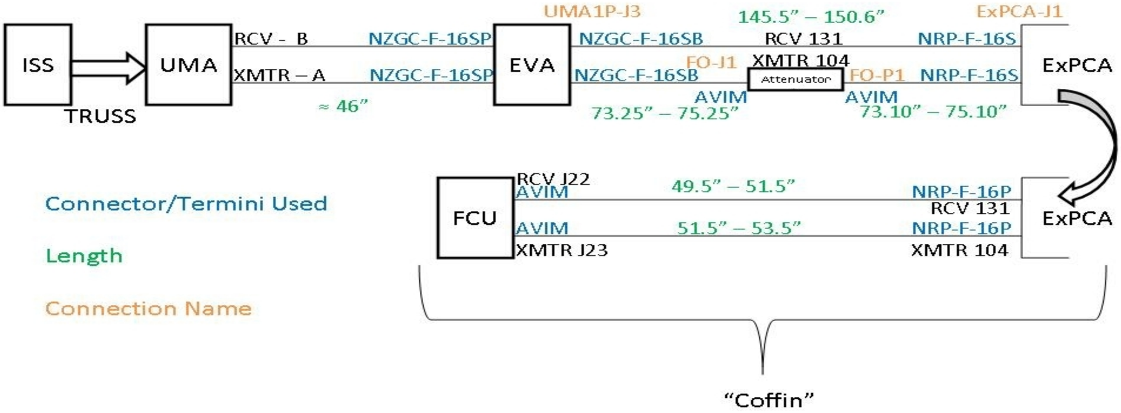
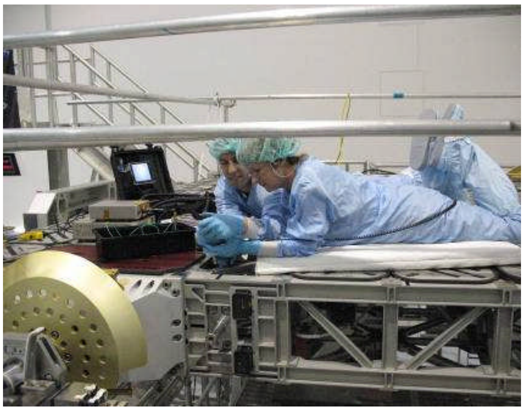


Fig. 5: Express Logistics Carrier Harness Flow Map

As shown in Figure 5, the FCU/ExPCA or "brains" of the pallet include the SPI optical fiber transceivers. The Photonics Group manufactured all optical fiber assemblies for the pallets and the transceivers. The 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 standard 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.

Due to the number of assemblies and the complexity of the integration, the subsystems are integrated in stages. The UMA (Umbilical Mechanism Assembly) arrived as supplied by Johnson Space Center with re-termination requirements 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 5 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. The attenuator which was described in section 2 was integrated here on each deck. 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.

Fig. 6: ELC team integrating optical assemblies



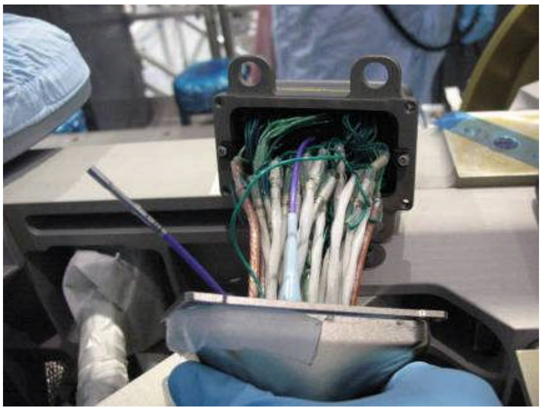


Fig. 7a: Photonics group team works at integration on ELC Deck 2 @ KSC ISS processing facility

Fig. 7b: Inside view of assemblies out of the back end of an ExPCA connector body

3.2 The Space Flight Qualified Space Station Optical Fiber Assemblies.

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 as mentioned in section 1 is “yes”. See “ISS Fiber Optic Failure Investigation Root Cause Report, Internal Report to NASA Headquarters” [1] for additional details.

A screening process was outlined in the 2000 report 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, 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, 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.

Figures 6 and 7 are pictures of the Photonics team working on integration issues. As is standard with the ISS MIL-STD 38999 type of optical interconnection, the integration tends to be overly complicated by the lack of sufficient insertion tools and the large mass of conductors pushed together with optical fiber harnessing into one back shell. The larger sized versions of these connectors require challenging integration maneuvers. The longer connector body grommet/insert reduce the effectiveness of the plastic insertion tool that cannot traverse the entire depth. The sockets themselves introduce damage to the softer inner grommet so that once the sockets are in place, grommet material has to often be removed carefully as to not contaminate the optical fiber endfaces prior to interconnection. At one point integration had to be stopped at Goddard Space Flight Center and resumed at Kennedy Space Center due to complications of harness/integration planning. Populating the connector with wire harnessing conductors prior to fiber integration, only complicates the integration of the optical fiber assemblies if the back shell is filled full of ground wires.

Conclusions

The ELC Pallets will complete integration by year end. Several valuable lessons learned can be passed on as a result of the experiences gained. Based on testing results with the simulator systems, the ISS specifications include more than sufficient margin (perhaps too much) on the transceiver specifications for transmission power and Re. Due to this, no additional system margin allocations are required at the subsystem (like ELC) or instrument level for mating equipment to the HRDL. When using the HRDL system specification, the requirements should be updated to include the advances made in detector technology and checked for system level effectiveness as they are written. The levels written into specification should be considered for feasibility for the case of lower loss fiber existing in the paths between the links in the HRDL.

Extensive integration of multiple harnessing into the ISS standard connectors require systematic planning such that less time is wasted with complications related to problems with insufficient tooling.

References

1 J.F. Plante, H.W. Leidecker, et al. *ISS Fiber Optic Failure Investigation Root Cause Report,* Internal Report to NASA Headquarters, 2000*.*

2. M. Ott*, Spaceflight Environmental Requirements for Optoelectronic Technologies for NASA Missions and NASA Technology Needs,* Invited Presentation to the International Symposium on Reliability of Optoelectronics for Space, Cagliari, 2009.

3. For more information and references please see the website http://photonics.gsfc.nasa.gov