Space Flight Applications of Optical Fiber Components
32 Years of Mission Success
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Outline

• Introductions - Who
• Successful usage of aerospace optical fiber systems – What, Where, & When.
• Example details
• Conclusion
## A Decade of Service from the Photonics Group for Photonics & Optical Fiber Components and Assemblies Code 562, Electrical Engineering Division of AETD, NASA GSFC

<table>
<thead>
<tr>
<th>Project</th>
<th>Dates</th>
<th>Design</th>
<th>Qualification</th>
<th>Manufacturing</th>
<th>Integration</th>
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<tr>
<td>ICESAT, GLAS,</td>
<td>1997 - 2005</td>
<td>X</td>
<td>X</td>
<td>GSE</td>
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<td>Prototype</td>
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<tr>
<td>ISS</td>
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<td>Lunar Orbiter Laser Altimeter</td>
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<td>Cryo GSE</td>
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<td>X</td>
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<td>Lunar Laser Comm Demo</td>
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<td>X</td>
<td>X</td>
<td>GSE / Cryo</td>
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</table>
Historical Overview of Fiber Optics in Space
1978 - 1999

• 1978-1980, Long Duration Exposure Facility (LDEF)
  – Passive optical fibers and fiber links

• 1989, Cosmic Background Explorer (COBE) satellite
  (P.I. Nobel Prize for Physics – GSFC’s Dr. John Mather)
  – Used photodiodes and optical fibers in a position and motion sensing of a mirror
  – Several erroneous position determinations observed
  – Little mission impact

• 1993, Photonic Space Experiment (Boeing)
  – Optical Fiber Radiation Experiment
  – Passive Components Experiment
  – Strained quantum well laser and custom boardband LED experiments
  – Bit Error Rate experiment
# Current Fiber Data Links
(based on 1999 survey presentation)

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>LAUNCH</th>
<th>TECHNOLOGY</th>
<th>SYSTEM WAVELENGTH</th>
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<td>AS1773 20Mbps</td>
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<td>MAP</td>
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<td>1300nm</td>
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<td>XTE</td>
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<td>PSE</td>
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<td>TRMM, et al.</td>
<td>11/97</td>
<td>MIL- STD-1773 1Mbps</td>
<td>850nm</td>
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</tbody>
</table>

Small Explorers (SMEX)

- Transceivers fabricated by SCI
  - TI photonics parts.
- Still functioning, last reaction wheel lost a few months ago, space craft still functioning.
- Power positive, spinning but functional for science data.
- First solid state recorder flown.
Hubble Space Telescope

- Solid state recorder UTMC protocol chips,
- Boeing transceivers. FO-1773
- Cooprocessor, SM2, 1993
- Servicing, 1995 -1997
- Still functional.

Space Borne Fiber Optic Data Bus

- Parallel Fiber Optic Data Bus, 1393
- ONI (Optivision) later became Space Photonics.
- First flight EO-1, cancelled during integration for funding issues, other instrument over budget.
- MTP Connector – Parallel
- Sandia now using optical fiber assemblies due to qualification of these assemblies during GSFC program.
Instruments & Communications
(since 1999)

• **International Space Station, US LAB 2001**
  – 125 Mbps, FDDI called High Rate Data Link (HRDL),
  – MIL 38999 Connectors w/ MIL 29504 Termini
  – Sent with cracked fiber, half being used, working NO REPORTED IMPACT.
  – GSFC lead failure analysis found during integration
  – Rocket engine defects are screened for and replaced during integration where possible.

• **Geoscience Laser Altimeter on ICESAT** (2003 launch)
  – Multi and single mode fibers, AVIM,
  – 2 Km of fiber used for delay line.
  – Confirms global warming

• **Mercury Laser Altimeter**, (2004 launch)
  – Receiver optic System(AVIM, Flexlite, Multimode Fiber)
  – Longest laser link established through space 24 MKm
  – Currently sending data from Mercury.
Instruments & Communications
(1999 - 2009)

• **Shuttle-Return-to-Flight**
  – NEPTEC high definition laser sensor camera
  – Optical fiber assemblies for laser and receiver optics
  – Terminated @ GSFC,
  – Packaging and failure analysis support for individual vendors.

• **GLAST**, using wavelength shifting fibers (launched 6-11-08)

• **Laser Ranging and Lunar Orbiter Laser Altimeter** (LRO launch 11-08)
  – Array bundles as part of receiver optical systems
  – LR Assemblies 10 m of 7 fiber bundles across 3 subsystems.

• **Express Logistics Carrier interface to ISS (ELC)**
  – (smart warehouse)
  – Space Photonics Transceivers, In house Electronics
  – In house manufacturing of Optical Fiber Harnessing.
Receiver telescopes focused into optical fiber assemblies that route to different detectors. The MLA is aboard MESSENGER on its way to Mercury!
The 24 Million Km Link with the Mercury Laser Altimeter

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

MOLA Science Team Meeting
Bishop’s Lodge, Santa Fe, NM
August 24-25, 2005
The Lunar Reconnaissance Orbiter; The Laser Ranging Mission and the Lunar Orbiter Laser Altimeter

(HGAS) High Gain Antenna System

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

Lunar Orbiter Laser Altimeter (LOLA)
NASA GSFC Fiber Optic Array Assemblies for the Lunar Reconnaissance Orbiter

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

**Laser Ranging (LR) for LRO Assemblies**
Description: 7 Fiber Array on both Sides in AVIM PM Connector
Wavelength: 532 nm
Quantity ~ 9 Assemblies ~ 1 to 4 m long each
LOLA Integration, October 2007
LR Segment 3 Flight Routing, April 2008
Additional Pictures of LRO, June 2008
Integration Complete
LOLA Progress

Altitude measurements of the south pole from the Lunar Orbiter Laser Altimeter (LOLA) instrument aboard the Lunar Reconnaissance Orbiter. Permanently shadowed areas are coldest, and confirmed to hold ice; permanently illuminated areas may be good spots for solar power stations.

Mars Science Lab, Chem Cam
AVIM connectors – Flexlite Cable
**Mars Science Lab – ChemCam Optical Assemblies, Launch delayed.**

Similar application as LRO
- Simplex Assemblies for receiver optics to spectrometer.
- Tried large core, 300/330 micron acrylate fiber from Nufern for flat broad spectrum with small NA=.13, unstable to bending, evaluated for radiation, W.L. Gore FON 1442, PEEK outer diameter 2.8 mm.
- Changed W.L. Gore Flexlite simplex FON1482 with FVA300330500 Polymicro, NA=.22.
- Diamond AVIM connector, custom drilling.
- Across gimbal system for -135°C to +70°C survival, -80°C to +50°C operational, +110 C high temp bakeout due to decontamination process.
- Manufacturing, Environmental Testing including; thermal, vibration, radiation
  - Thermal -50°C to +80°C, for 30 cycles as a validation of the termination process.
  - Vibration, JPL custom profile ~ 7.9 grms, and 14.1 grms GSFC typical.
  - Radiation comparison analysis performed, based on data from previous missions.
Express Logistics Carrier (ELC modules) “Smart Warehouse for Station”
Express Logistics Carrier for ISS; Communications System Assemblies

GSFC Photonics Group –
Flight Control Unit Transceiver Assemblies
(Space Photonics) SPI- FCU Transceivers
GSFC Photonics Group - Harnessing
## Subsystem Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Manufacturer</th>
<th>Part Number/ Identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transceivers for FCU</td>
<td>Space Photonics</td>
<td>HMP1-TRX</td>
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<tr>
<td>Transceiver Interconnection</td>
<td>Diamond</td>
<td>AVIM</td>
</tr>
<tr>
<td>Transceiver Optical Fiber</td>
<td>Nufern</td>
<td>FUD-2940</td>
</tr>
<tr>
<td>Transceiver Cable</td>
<td>W.L Gore</td>
<td>Flexlite, simplex FON1435</td>
</tr>
<tr>
<td>ExPCA Interconnection</td>
<td>Sabritec</td>
<td>SSQ22680</td>
</tr>
<tr>
<td>ExPCA Termini</td>
<td>ITT Canon</td>
<td>SSQ21636-NRP-F-16 (S,P)</td>
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<tr>
<td>Harness Optical Cable</td>
<td>BICC</td>
<td>SSQ21654-NFOC-2FFF-1GRP-1 (Obsolete)</td>
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<tr>
<td>Attenuator</td>
<td>GSFC/Diamond</td>
<td>Cleanable AVIM Adapter</td>
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<tr>
<td>Attenuator Interconnection</td>
<td>Diamond</td>
<td>AVIM</td>
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<tr>
<td>EVA Connector Circular</td>
<td>Amphenol</td>
<td>SSQ21635</td>
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<td>EVA Termini</td>
<td>ITT Canon</td>
<td>SSQ21635-NZGC-F-16 (SB,PB)</td>
</tr>
<tr>
<td>ISS-UMA Connector</td>
<td>ISS Supplied</td>
<td>ISS Supplied</td>
</tr>
</tbody>
</table>

### Diagram

- **ISS**
- **UMA**
- **Express Pallet**
- **Flight Control Unit (FCU)**
- **EVA Interconnection**
- **ExPCA Interconnection**
Express Logistics Carrier, Connection to ISS
AVIM connectors – Flexlite Cable

Fiber Optic Flight Assemblies for Space Photonics Transceivers
Harnessing Diagram for Express Logistics Carrier on ISS

Connectors/Termini Used

- RCV - B NZGC-F-16SP
- NZGC-F-16SB
- NZGC-F-16SB
- AVIM
- AVIM
- AVIM
- AVIM
- RCV J22
- AVIM
- RCV 131
- AVIM
- 51.5" – 53.5"
- NRP-F-16P
- 49.5" – 51.5"
- NRP-F-16S
- 73.25" – 75.25"
- 145.5" – 150.6"
- NRP-F-16S
- 73.10" – 75.10"
- RCV 131
- XMTR 104
- XMTR J23
- XMTR 104
- XMTR J23
- XMTR 104

Length

Connection Name

ExPCA Connector
Integration of the ELC assemblies at KSC International Space Station Facility

Last assemblies to integrate into the harnessing were the optical fiber assemblies, reason = risk mitigation. Schedule constraints led to integration at the International Space Station Processing Facility at Kennedy Space Center. Lesson Learned= Integrate sooner.
MISSE-7 the 7th Materials International Space Station Experiment Installed. High Pressure Gas Tank were installed by the STS-129 Crew on November 23rd 2009 on From ELC-2 to Quest Airlock for entering space walkers.
On November 18 2009 Space Shuttle Atlantis and the International Space Station (ISS) astronauts attached the ExPRESS Logistics Carrier-1 (ELC) to the Earth-facing side of the station’s left truss, or backbone. This is the first of two ELCs that will be installed on the station’s exterior during STS-129, providing easily-accessible spares to increase the longevity of the station. Designed and built at Goddard, this newly formed project designed, built, and tested five unpressurized aluminum carriers and six avionics packages for bringing spare hardware and science to the ISS.

GSFC Dateline November 19 2009
ISS Connector/Pin Anomaly

When we use older technologies we continue to complain about optical fiber being “complicated”
ExPCA Connector Anomaly Investigation

Why did the pins break off?

SSQ21636-NRP-F-16 Mated Pair

Pin: SSQ21636-NRP-F-16P

Socket: SSQ21636-NRP-F-16S

Gap between Ceramic and Metal Shell

Socket does not engage the entire pin, leaving joint vulnerable

X-Ray Image
SSQ21635 & SSQ21636 Termini

Designed to make breakage more likely at ceramic/metal shell interface
Military 29504 Specification no longer supports this slash sheet (drawing)

Longer Version NRP-F-16P (S)

Shorter Version NZGC-F-16-PB (SB)

Lesson Learned: Support the Development of Current Standards: JEDEC & SAE
James Webb Space Telescope (JWST) Optical Telescope Element Simulator

Cryogenic Optical Assemblies for GSFC “Super Ferrule” Connector Design
For simulation of 600 nm to 5600 nm for JWST.
Types of Optical Fiber Tested in Diamond ceramic shell titanium ferrules and FC connectors with and without crimp:
1) Fibercore, Single mode types, SM600 & SM900.
2) Infrared Fiber Systems, ZBLAN doped, 200 micron
3) CorActive AsSe 30 micron

Cryogenic Validation Testing:
To less than 100 Kelvin
For OSIM integration the required Cryo assemblies are:
Side A: Ceramic/Titanium ferrules, Side B: Diamond FC
The MTP Connector for Communications
Support to NASA & DOE, Sandia
Qualification Testing of the MTP, 1998 - 2009
NASA Electronic Parts & Packaging Program (NEPP)
Radiation Database 2008

http://nepp.nasa.gov
### Multimode Fiber Descriptions Summary Table

<table>
<thead>
<tr>
<th>Fiber ID</th>
<th>Manufacturer</th>
<th>Part Number</th>
<th>Fiber Description</th>
<th>Ref#</th>
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<td>MM-021002</td>
<td>Heraeus</td>
<td>SSU 1.2 107/00</td>
<td>Step Index; 104/125/250; 0.22na; High OH Low Cl; CCDR 1.2; 40m &amp; 70m</td>
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<td>MM-021004</td>
<td>Mitsubishi Rayon</td>
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<td>MM-021005</td>
<td>FORC</td>
<td>KS-4V</td>
<td>Step Index; 110/125/280; 0.6 OH</td>
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<td>MM-022204</td>
<td>Fujikura Ltd.</td>
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<td>MM-031101</td>
<td>Polymicro</td>
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<td>300/330/370; 0.7m - 1.68m Length</td>
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<td>MM-031102</td>
<td>Polymicro</td>
<td>FIP300330370</td>
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<td>MM-031401</td>
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<td>FIA200220500</td>
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<td>MM-051201</td>
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<td>FI4369</td>
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<td>MM-051202</td>
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<td>50/125; Graded-Index; &lt;10m Length; Rad-Hard</td>
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<td>MM-061701</td>
<td>Nufern</td>
<td>GR 100/140-24-HTA</td>
<td>12-Fiber 100/140 Graded-Index; 6.35m; Rad-Hard; W.L.Gore FOA 8100/12/1</td>
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<td>MM-071101</td>
<td>ThorLabs</td>
<td>BFL37-200</td>
<td>200/230; Low OH; 50m Length</td>
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<td>MM-071102</td>
<td>ThorLabs</td>
<td>BFH37-200</td>
<td>200/230; High OH; 50m Length</td>
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<td>MM-072101</td>
<td>Polymicro</td>
<td>FIA200220500</td>
<td>200/220/500; Acrylate; 0.22NA; W.L. Gore FON1173 10m Length</td>
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<td>MM-072201</td>
<td>Polymicro</td>
<td>FIA400440580</td>
<td>400/440/500; Acrylate; 0.22NA; W.L. Gore FON1416; 9.5m Length</td>
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<td>MM-090103</td>
<td>Draka</td>
<td>RadHard SMF</td>
<td>DRAKA Elite 50/125/242; 1km length</td>
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<td>MM-090104</td>
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<td>Super RadHard SMF</td>
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# NEPP Optical Fiber Radiation Database

## Radiation Effects Summary Multimode Candidates

### Multimode Fiber Radiation Effects Summary Table

<table>
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<th>Fiber ID</th>
<th>λ(nm)</th>
<th>Dose Rate (Gamma)</th>
<th>Total Dose (Gamma)</th>
<th>Temp</th>
<th>Attenuation (dB/m)</th>
<th>Details</th>
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<tbody>
<tr>
<td>MM-021002</td>
<td>829nm</td>
<td>125 rads/s</td>
<td>1M rads</td>
<td>25°C</td>
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<td>MM-021002</td>
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<td>300 krad/s</td>
<td>25°C</td>
<td>0.008</td>
<td>Graph Data</td>
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<tr>
<td>MM-021002</td>
<td>829nm</td>
<td>125 rads/s</td>
<td>100 krad/s</td>
<td>25°C</td>
<td>0.0065</td>
<td>Graph Data</td>
<td>[1]</td>
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<tr>
<td>MM-021002</td>
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<td>125 rads/s</td>
<td>30 krad/s</td>
<td>25°C</td>
<td>0.005</td>
<td>Graph Data</td>
<td>[1]</td>
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</table>
References for the Radiation Database 2008


NASA Electronic Parts and Packaging Program
Component Evaluations for Small Form Factor Applications

As a technology validation of the Diamond DMI (Mini AVIM) for space form factor applications the following tests were conducted:

- Pull Force Data
- Thermal Testing
- Vibration Testing

Space Version

Rugged Version

Standard Version

Rugged Version
<table>
<thead>
<tr>
<th>Project</th>
<th>Dev</th>
<th>Launch</th>
<th>Connectors</th>
<th>Description</th>
<th>Details</th>
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<tr>
<td>Geoscience Laser Altimeter System (GLAS) on ICESAT</td>
<td>1998</td>
<td>2001</td>
<td>AVIM Standard, Single Mode / Multi Mode / Flat Polish, 2 Km of SM</td>
<td>Gore Flexlite SM &amp; MM</td>
<td>Custom drill in ferrule, tungsten carbide shell ferrules</td>
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<td>Mercury Laser Altimeter (MLA) MESSENGER</td>
<td>2001</td>
<td>2004</td>
<td>AVIM Standard, Flat Polish</td>
<td>330 um MM Flexlite</td>
<td>Custom drill in ferrule, tungsten carbide shell ferrules</td>
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<td>Lunar Orbiter Laser Altimeter on Lunar Recon Orbiter</td>
<td>2007</td>
<td>2009</td>
<td>AVIM array connector, 303 SS ferrule drill @ GSFC</td>
<td>SS larger PM AVIM for 5 220 um fibers side one, fan out standard side two, Flexlite</td>
<td>Custom drill 220 um on fan out side, with standard AVIM tungsten carbide shell ferrules</td>
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<td>Laser Ranging on Lunar Recon Orbiter</td>
<td>2007</td>
<td>2009</td>
<td>AVIM Array connector, 416 SS ferrule flower drill @ Diamond</td>
<td>SS larger PM AVIM for 7 440 um fibers, large custom cable</td>
<td>Both sides array flower pattern. Gimbal, cold, to -55 C.</td>
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<td>Mars Science Lab, Chemcam</td>
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<td>AVIM standard custom drill ferrule for 330 um</td>
<td>Flexlite</td>
<td>Gimbal, cold, hot to 110 C.</td>
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<td>Express Logistics Carrier on ISS</td>
<td>2008</td>
<td>Nov-2009</td>
<td>AVIM standard custom drill for 140 um</td>
<td>Space Station cable &amp; Flexlite</td>
<td>Pilz ceramic shell ferrules</td>
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<tr>
<td>NASA GSFC evaluation of Mini AVIM &amp; DMI</td>
<td>2008</td>
<td>none</td>
<td>Bare fiber for thermal and vibration testing.</td>
<td>No cable, cryogenic application.</td>
<td>Multiple sizes, multiple materials</td>
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<tr>
<td>James Webb Space Telescope</td>
<td>2008</td>
<td>GSE</td>
<td>FC &amp; AVIM titanium ferrules.</td>
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</table>

Some Lessons Learned

- Know your failure modes or hire an expert to do it for you.
  - Materials analysis now or later, you decide.
  - Vendors get information from outgassing database – it's not stand alone

- Cracked fiber may not mean catastrophic failure unless you are photon counting. Example ISS.

- Need experts to review documentation.

- Need good quality documentation;
  - Pre-manufacturing preconditioning of materials.
  - Incoming inspection of all vendor supplied items.
  - Manufacturing procedures.
  - Post manufacturing visual inspections for compliance.
  - Post manufacturing workmanship.
Conclusions

• Redundancy is used to reduce risk in communication systems.
• Optical fiber systems have been used in space flight for thirty years successfully.
• Knowledge of failure modes and materials is crucial to making feasibility decisions as well as design, manufacturing procedures and test plans.

• Technology Needs for Near Term Future
  ✓ IR Photonics out to 10 um,
  ✓ Smaller packaging,
  ✓ Cyrogenic applications
  ✓ Outsourcing for LIDAR lasers.
  ✓ Fiber lasers for LIDAR, Science & Comm
  ✓ High power optical fiber assemblies
  ✓ General LIDAR & Laser communications components

Thank you!

For more information please visit the website:
http://photonics.gsfc.nasa.gov