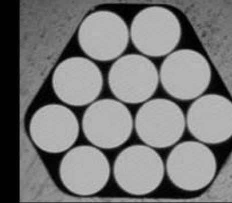
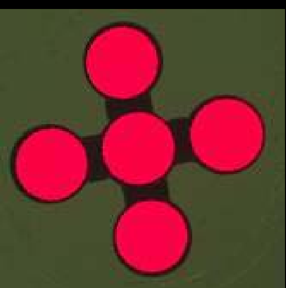
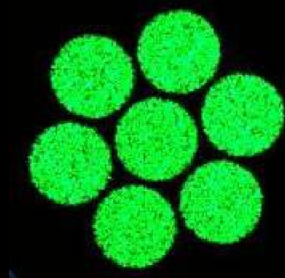
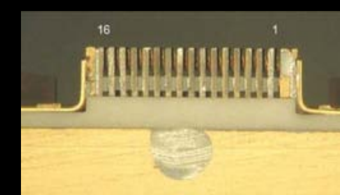
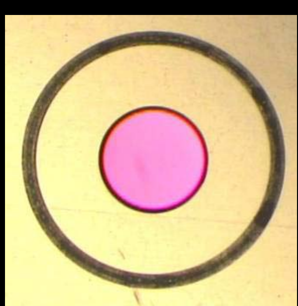




Implementation and Qualification Lessons Learned for Space Flight Photonic Components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Outline

- Introductions - Who
- Requirements
- Production Flow and Issues
- Inspections & Materials Processing
- Quality
- Testing, Performance vs. Qualification
  - Qualification defined by who
- Tools you can use
- Update on Current Projects

Lighting up Science with Innovation & Reliability

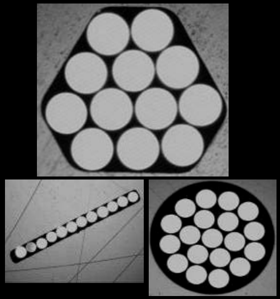
http://photonics.gsfc.nasa.gov

CODE 562 PHOTONICS Group @ GSFC

Design, Development, Manufacturing, and Full Hardware Environmental Validation & Integration
Optical Fiber Assemblies and Photonic Components
Arrays, Assemblies, and Components for: Spectrometers, Calibration Systems,
Communication Systems, Receiver Optics, Transmitter Optics, High Power Lasers,
Specialty Fiber Packaging Configurations

Cryogenic Optical Fiber Assemblies

FC Connector ferrule



Custom Bundle Arrays

Optical Modulator

Laser Diode

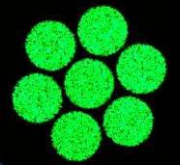
Component TRL Enhancement & Qualification

Communications Assemblies

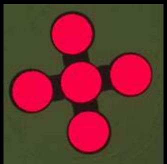
Optical fiber 200X endface

LRO: **Concept to Flight Hardware Integration: 18 months**
Array assemblies in a flight connector developed and fabricated for Laser Ranging; Seven Optical Fiber Array, 10 meters long, 2 interconnects.
LOLA – Five Optical Fiber Array for Receiver Optics

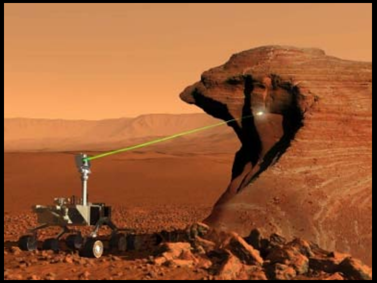
Laser Ranging @ 532 nm on LRO



LOLA @ 1064 nm on LRO



MSL Chem Cam: **Optical Assemblies for Gimbal/ Receiver Optics**



Melanie N. Ott, Group Lead 301-286-0127

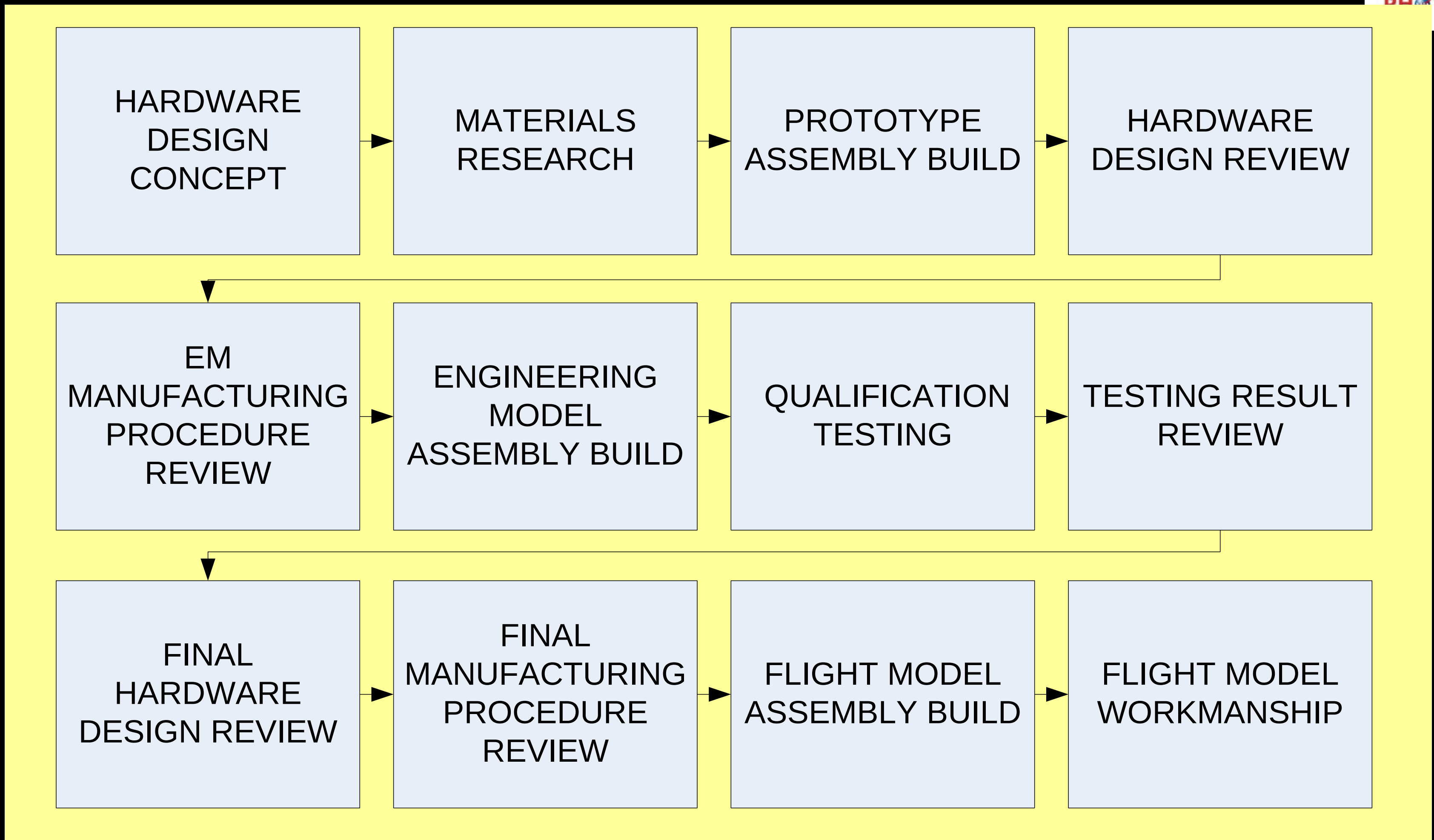
A Decade of Service from the Photonics Group for Photonics & Optical Fiber Components and Assemblies Code 562, Electrical Engineering Division of AETD, NASA GSFC

GSFC

CODE 562 PHOTONICS Group @ GSFC

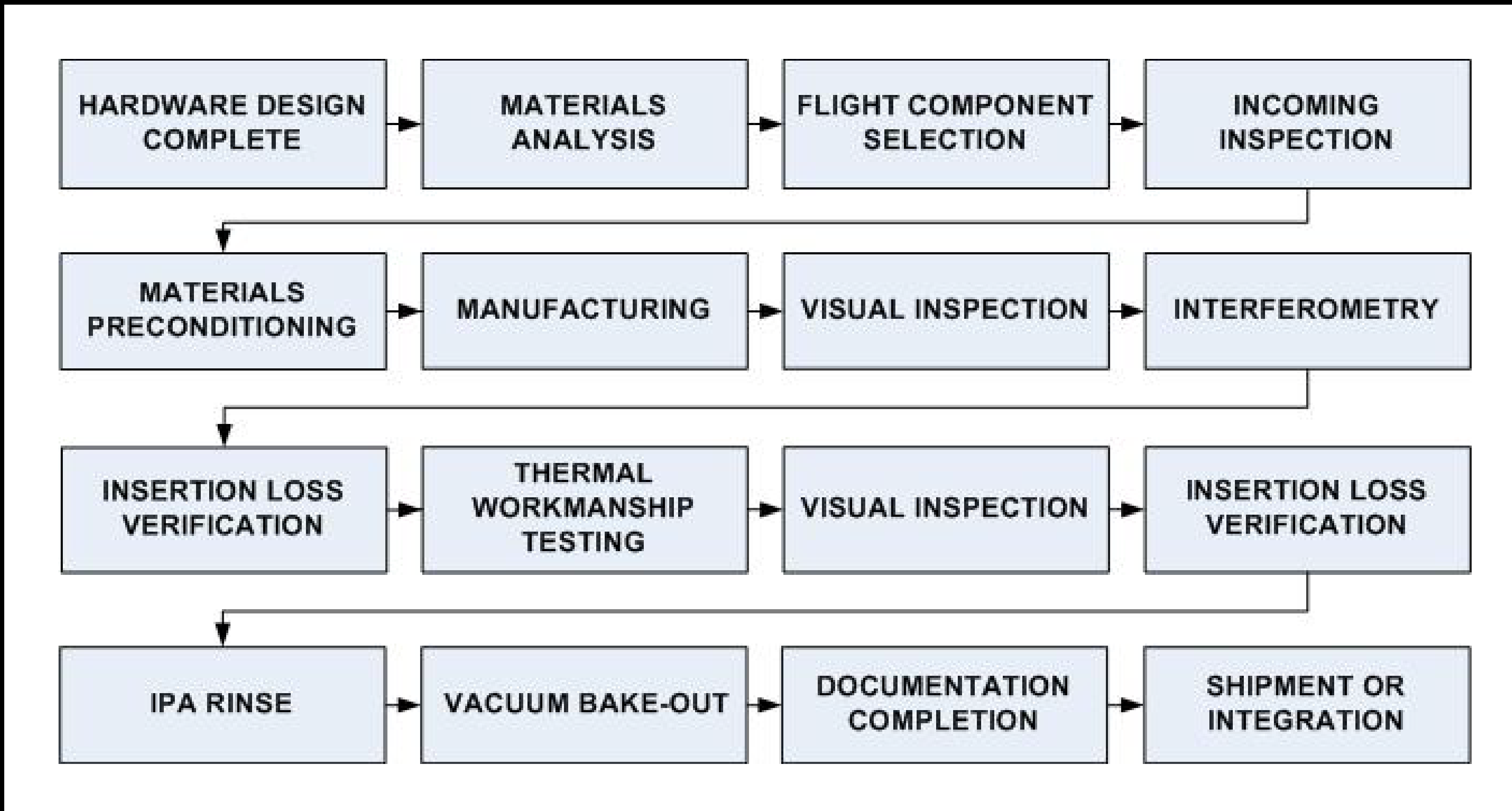
Project	Dates	Design	Qualification Performance over Harsh Environment	Manufacturing	Integration	Failure Analysis
ICESAT, GLAS,	1997 - 2005	X	X	GSE		Prototype
ISS	1998 - 2008					Vendor/ Flight
ISS - HDTV	2003	X	X	FLIGHT		
Fiber Optic Data Bus	1997 -2000	X	X			
Messenger – MLA,	2001 - 2004	X	X	FLIGHT	X	
Sandia National Labs (DOE)	1998 -2010		FLIGHT			Vendor/ Flight
ISS-Express Logistics Career	2006 -2010	X	X	FLIGHT	X	
Air Force Research Lab	2003, 2008, 2010		X			
Shuttle Return To Flight	2004 -2005			FLIGHT		
Lunar Orbiter Laser Altimeter	2003 -2008	X	X	FLIGHT	X	Prototype
Hubble Servicing Mission 4	2006			GSE		
Mars Science Lab ChemCam	2005 -2008	X	X	FLIGHT	X	Vendor
Laser Ranging, LRO	2005 - 2008	X	X	FLIGHT	X	Prototype
James Webb Space Telescope	2008 - 2009		X	Cryo GSE		
Fiber Laser & Laser IRADs	2003 - 2010	X	X	QUAL		
Lunar Laser Comm Demo	2009 - 2010	X	X	GSE / Cryo		

How Does the Photonics Group Go from Ideas to Flight?



BASIC PRODUCT LIFE CYCLE

Photonics Group General Production Flow For Flight Hardware



Most Common Anomalies Are Caused By:

- **Design Compatibility**
  - **(tolerances, materials, interconnection, CTE)**
  - **A packaged part is a mini integrated system**
- **Materials Selection**
  - **Outgassing Considerations (outgassing.nasa.gov)**
  - **Metals & Epoxies.**
- **Processing of Materials**
  - **Degassing of non compliant materials (if CVCM is low)**
  - **Thermal precondition polymers**
- **Incoming Inspection**
  - **Prior to Manufacturing**
  - **Prior to Integration**
- **Requirements vs. Manufacturing Parameters**
  - **Thermal Req. vs. Epoxy Cure Schedule & Polishing**
- **Workmanship**
  - **How do you test?**
- **Quality Controls & Documentation**
  - **Rigorous clear procedures & Quality Assurance Docs (QAD)**
- **Training: Integration & Handling**
  - **Documentation isn't enough, there is a long learning curve on handling.**

Perspective

Humans focus on the negative and tend to sensationalize it.

Why? We watch the news – it's become our culture.

Define Requirements,

Focus on what you are going to need in the reaching future.

The past provided lessons learned and are well documented.

Knowing the "how to" is more important than the "what"

There are more positives than negatives, good news travels like a snail and is often not remembered, while bad news travels at the speed of the internet!

Design Compatibility

Ferrule tolerances for custom designs -
(don’t plan on getting it right the first time)

Cable and Connectors are not mutually exclusive
(consider them an assembly for manufacture & qual

Heavily doped fibers tend to be brittle – packaging considerations

Example 1: ISS Cable Design

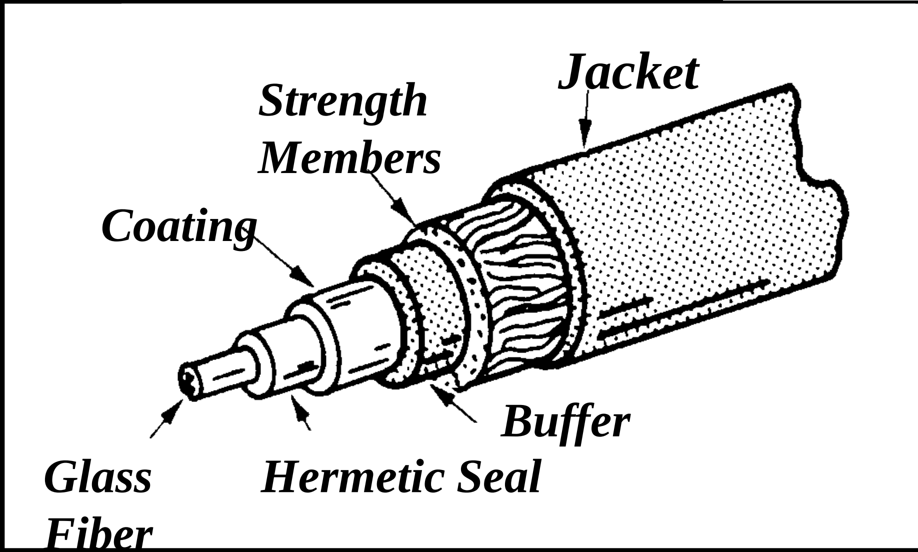
Example 2: GLAS Laser High Power Laser Diode Arrays

Example 3: ELC – ISS Connector Termini

International Space Station 2000, Lead by GSFC

Failure Analysis: Optical Fiber Cable 1999-2000

Failure Analysis: Optical Fiber Termini 2005-2006,
Lead by GSFC



Bad combination of physics

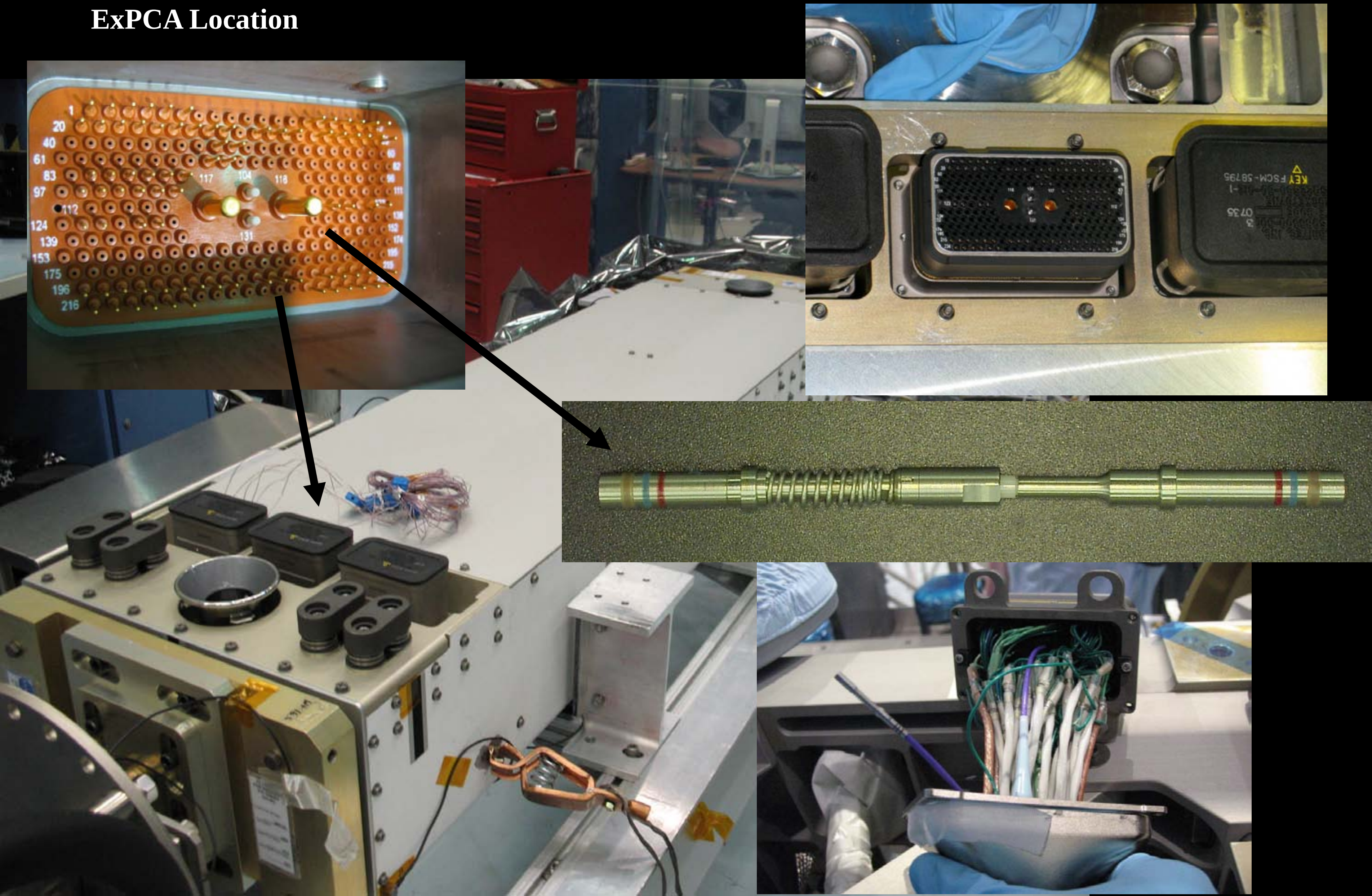
Fiber Optic Cable “Rocket Engine” Defects

- Hermetic coating holes,
- Polyimide coating holds water
- Fluorine generated during extrusion of buffer
- Hollow tube construction
  - water and fluorine interaction results in HF acid
- HF etches pits into fiber getting through holes in coating
- Etch pits deep into the core caused losses and cracks

Conclusion; We don’t recommend hermetic coatings.

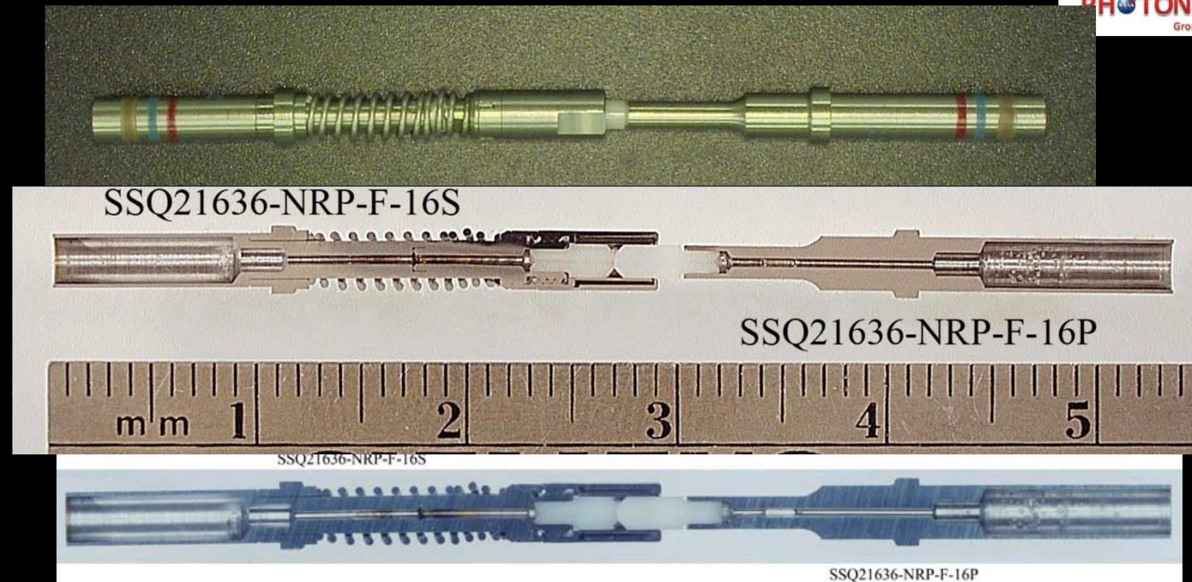
ISS Connector/Pin Anomaly

ExPCA Location



ExPCA Connector Anomaly Investigation

Why did the pins break off?



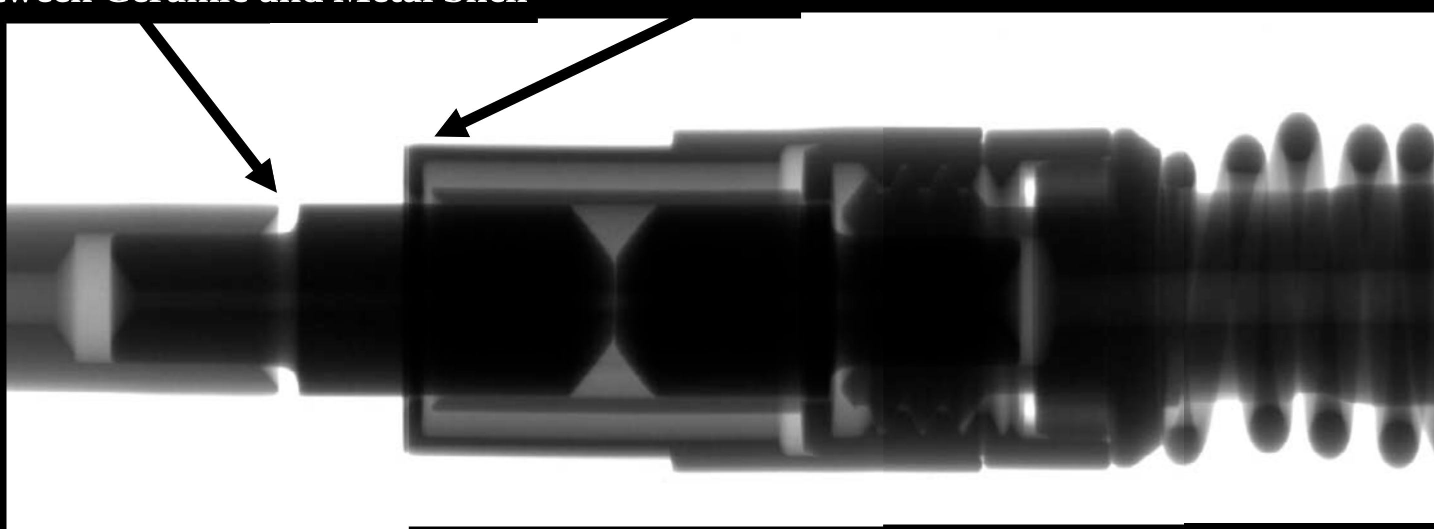
SSQ21636-NRP-F-16 Mated Pair

Pin: SSQ21636-NRP-F-16P

Socket: SSQ21636-NRP-F-16S

Gap between Ceramic and Metal Shell

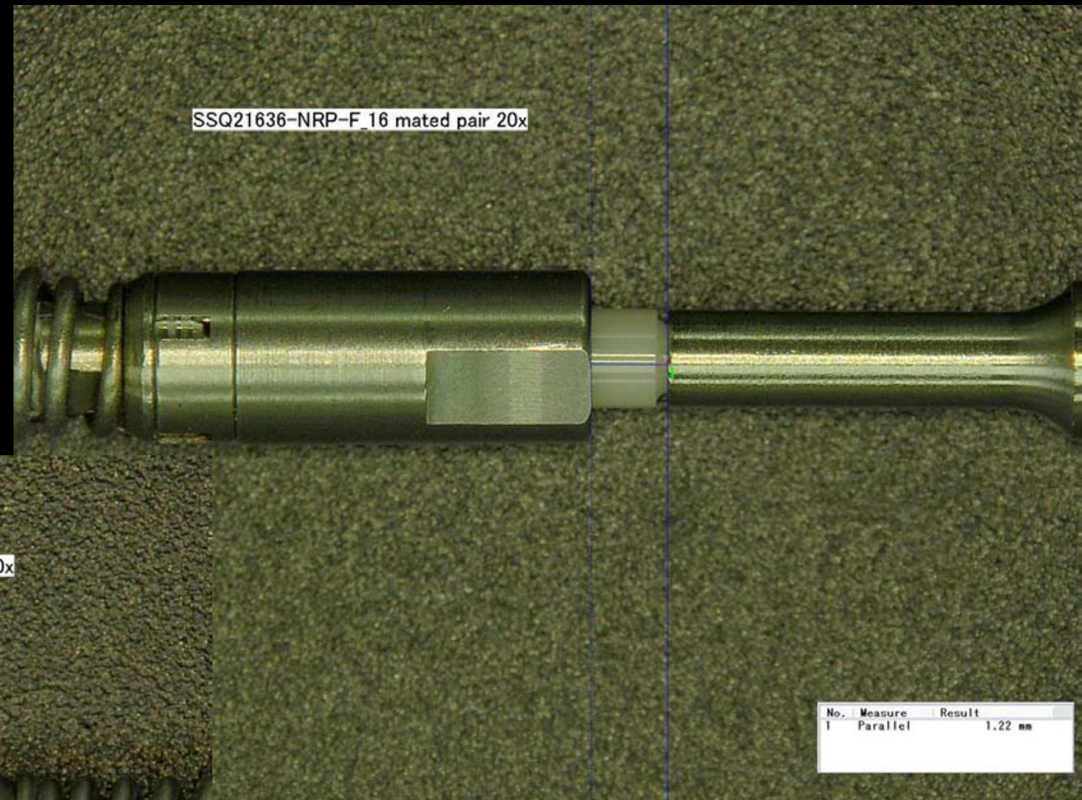
Socket does not engage the entire pin, leaving joint vulnerable

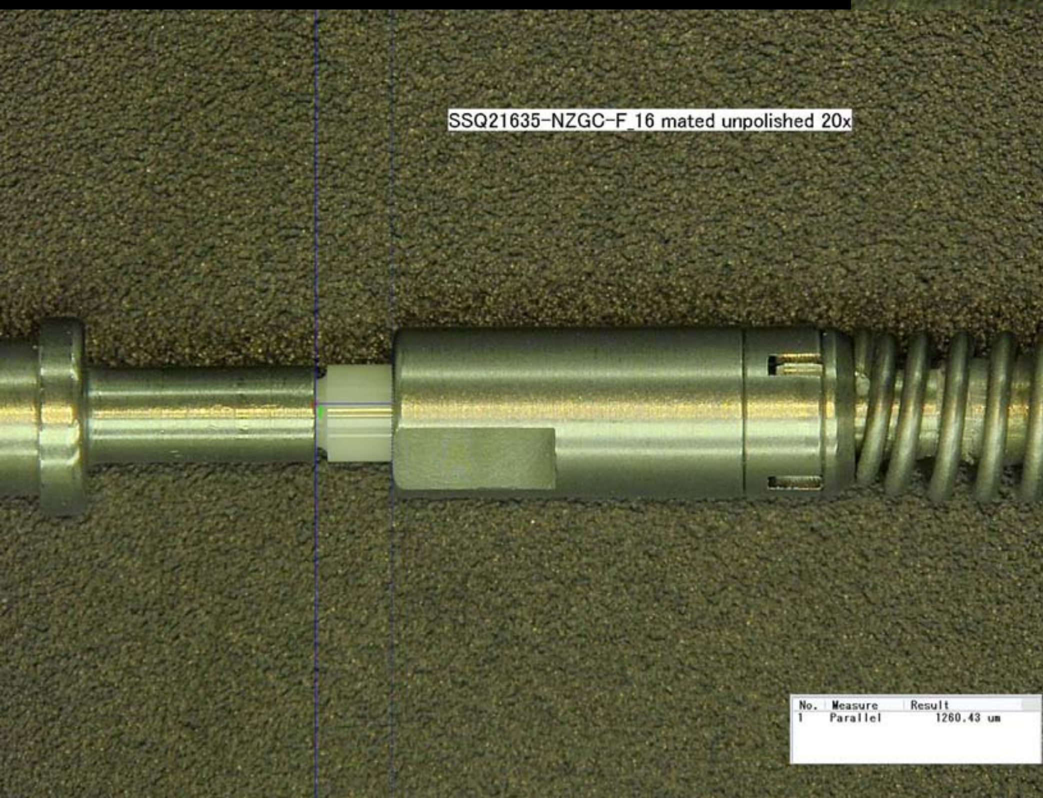


X-Ray Image

SSQ21635 & SSQ21636 Termini
Designed to make breakage more likely at ceramic/metal shell interface

Longer Version NRP-F-16P (S)

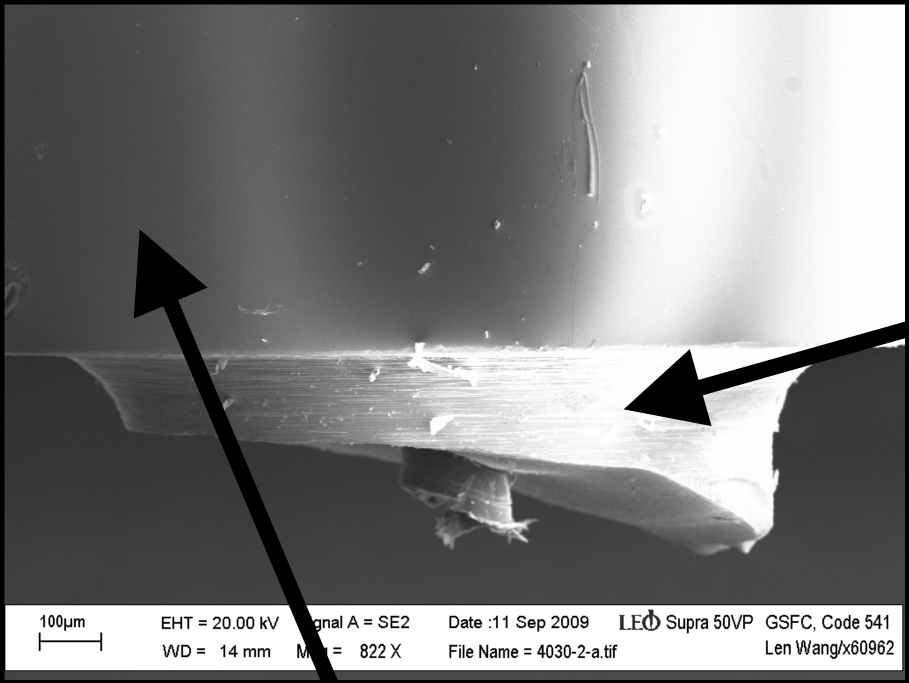




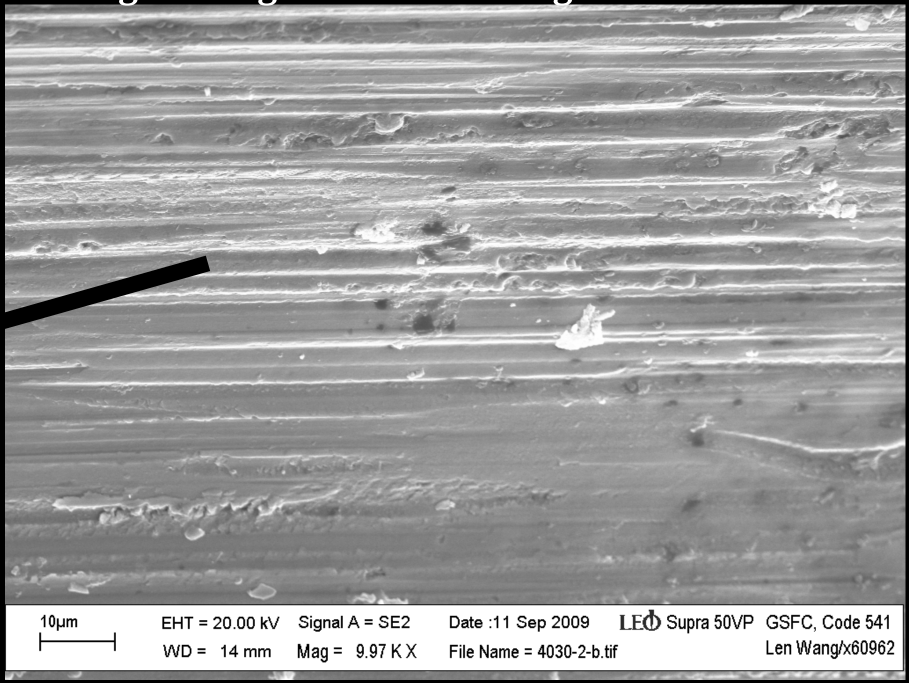
Shorter Version NZGC-F-16-PB (SB)

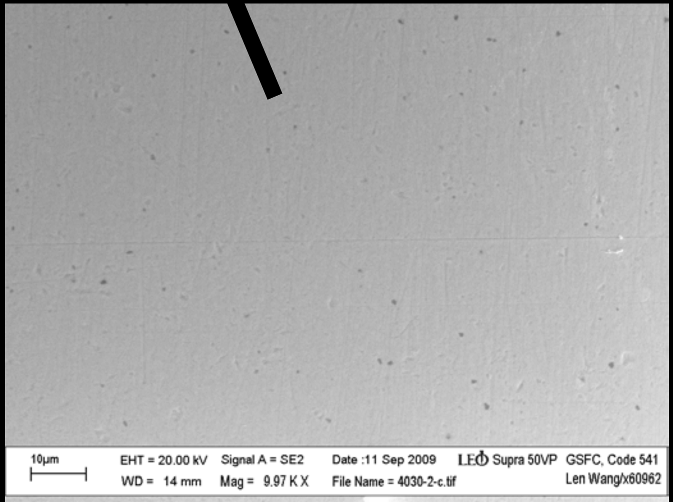
Surface Images of Pin

Side view of ceramic pin near crack region



Side view of ceramic pin near crack region
Higher magnification of rough area

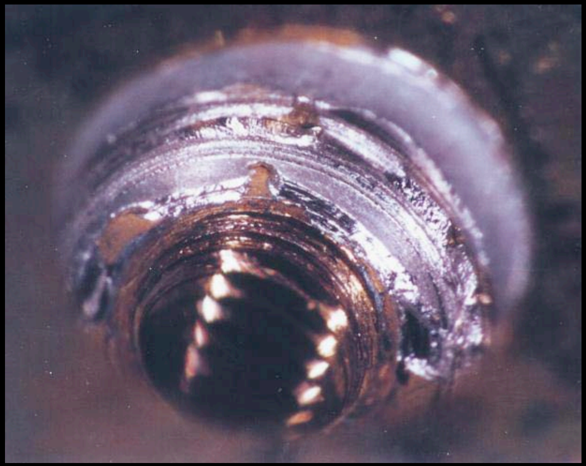




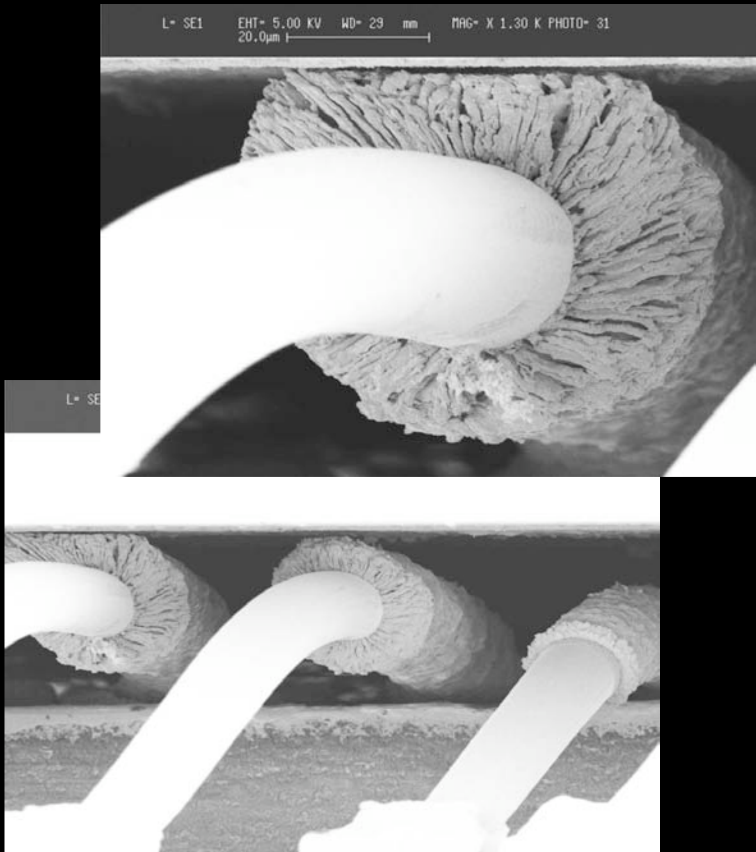
Side view of ceramic pin away from tapered region

Materials Selection

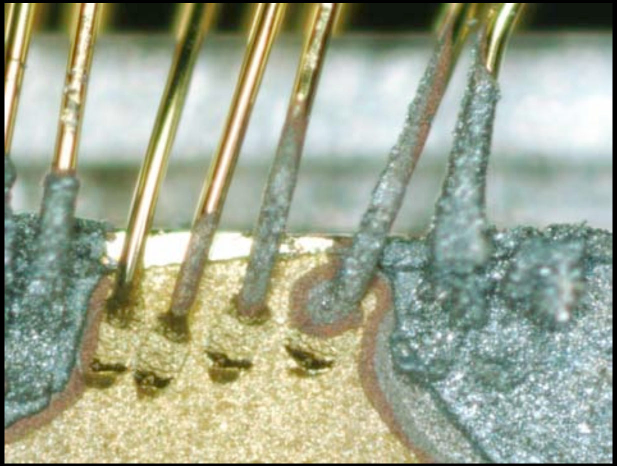
Laser Diode Packaging Issues



Device Short
Indium creep into bolt holes



Indium creep onto the gold wires
Intermetallic Gold/indium



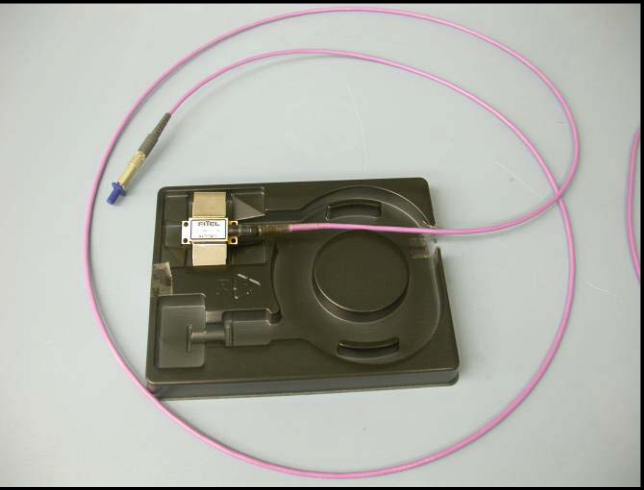
Pictures from Dr. Henning Leidecker's presentation "Failure Analysis of GLAS Laser Diode Arrays," Community Forum on Laser Diode Arrays in Space-Based Applications, 2004

Materials Issues: Shuttle Return to Flight

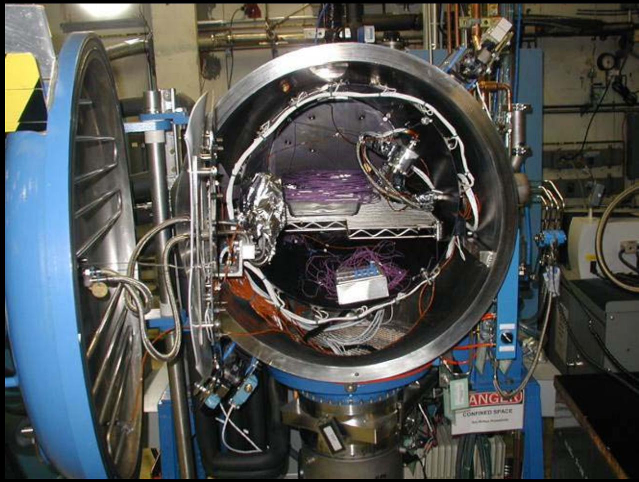
Laser Diode Assemblies

Fitel: laser diode pigtails
GSFC: Upjacket (cable), strain relief, termination, AVIMS APC SM
Fitel uses silicone boot, non-compliant!
Too late in fabrication process, schedule considerations to preprocess.

Cable: Thermal preconditioning, 30 cycles
Hytrel boots: Vacuum preconditioning, 24 hours
Kynar heat shrink tubing, epoxy: approved for space use.



Post manufacturing decontamination of entire assembly required
Laser diode rated for 85°C processing performed at 70°C



Materials Processing

- Degas items that have low CVCM but don't comply with ASTM-E595 due to larger than 1% Total Mass Loss.
- Thermal preconditioning on all fluoropolymers, use your survival requirements with margin.
- Cut product to approximate size prior to preconditioning.
- Validate that your epoxies have the appropriate hardness for your cure schedule.
- Acrylates are ok inside of a jacketed configuration even though they fail outgassing.

  If used for splicing, vacuum bake after and validate it for performance
- Be careful with making substitutions they may cause more failure modes

Materials Issues
Shuttle Return to Flight: Construction Analysis

Optical Fiber Pigtailed Collimator Assemblies

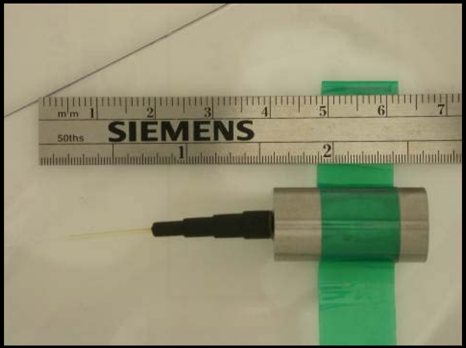
Lightpath: pigtailed fiber to collimator lens and shell

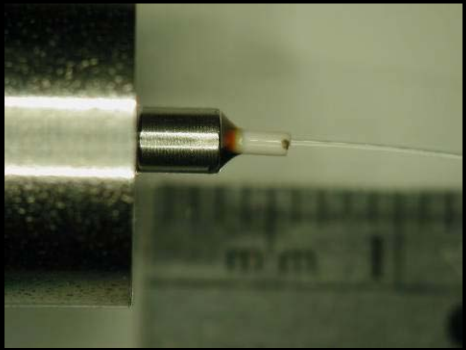
GSFC: upjacket (cable), strain relief and termination, AVIMS, PC, SM

Materials & Construction Analysis

- Non compliant UV curable adhesive for mounting lenses to case
  - Solution 1: replace with epoxy, caused cracking during thermal cycling
  - Solution 2: replace with Arathane, low glass transition temp. adhesive

  Lesson: coordinate with adhesives expert, care with adhesive changes.
- Hytrel, non compliant as an off the shelf product (outgassing, thermal shrinkage)
  - Thermal vacuum preconditioning (145°C, <1 Torr, 24 hours)
  - ASTM-E595 outgas test to verify post preconditioning.
  - Thermal cycling preconditioning (30 cycles, -20 to +85°C, 60 min at +85°C)





Workmanship

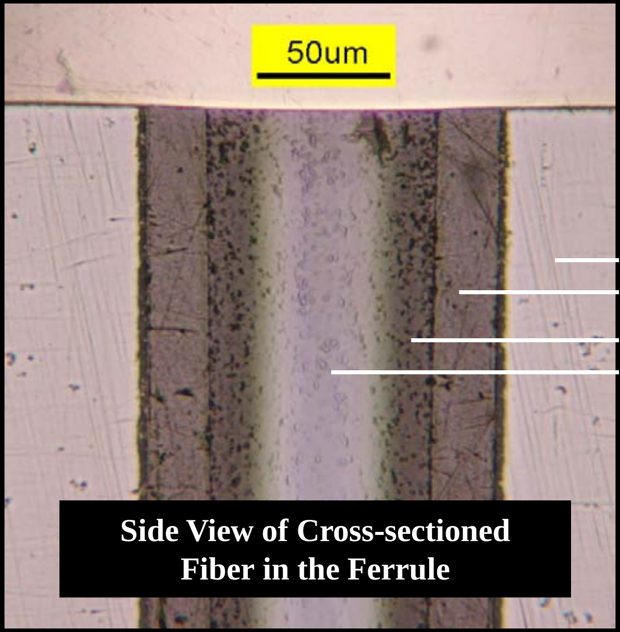
- As the manufacturer you should be performing workmanship testing
  - Final Inspections at very high magnification
  - Interferometry for optical fiber terminations
  - Mechanical
  - Thermal,
    - To “exercise” the packaging ;-25 °C to +75 °C for example, for 10 cycles, hour long dwells.
    - After thermal cycling, re-inspect and performance testing.

Incoming Inspection & Cleaning

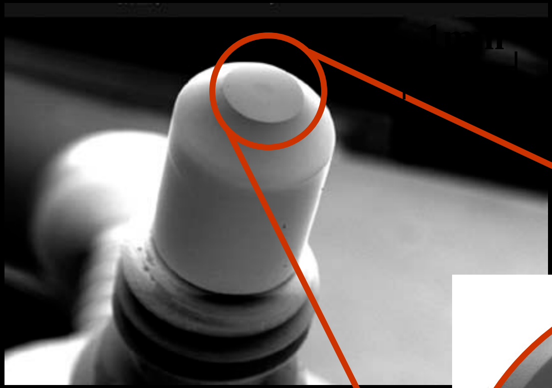
- Never neglect doing this.
- As a manufacturer or an integrator: visuals and validate documentation if at all possible – trust but verify.
- Just a few samples if the verification testing takes too long.
- Never connect anything together with out inspection and cleaning.

ISS Termini Failure Analysis

The below cross section of the terminus shows a concave end-face. This is per specification. If the end-face were convex, the glass would likely experience an impact when connected, causing a fracture.

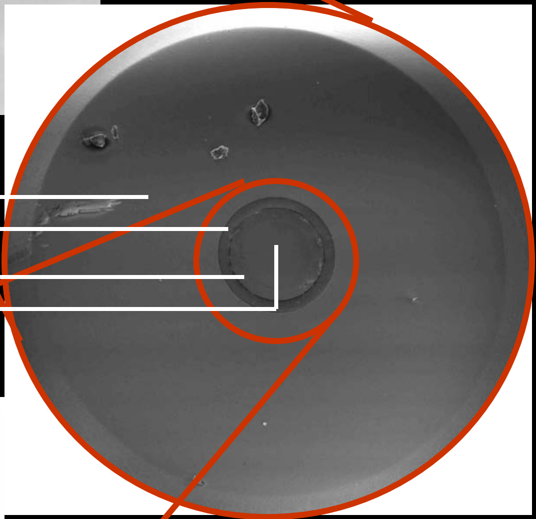


Side View of Cross-sectioned Fiber in the Ferrule



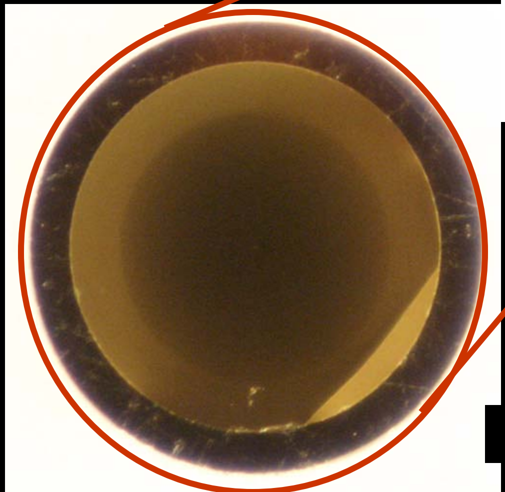
The fiber must be free of cracks in order to prevent a degraded or blocked optical signal. If a glass fiber has a crack after the polishing process, the crack will grow over time.

The termination is made up of:
- A zirconia ferrule
- Polyimide coating
- Pure silica cladding
- Germanium doped core



Ferrule & Fiber End View

The end-face of this optical fiber is 140µm. If dirt is present, the optical signal would be degraded or blocked.



Core, Cladding, & Coating End View

Quality Processes and Documentation

Laser Ranging on Lunar Recon Orbiter 2006-2008

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

MSL CM Documentation

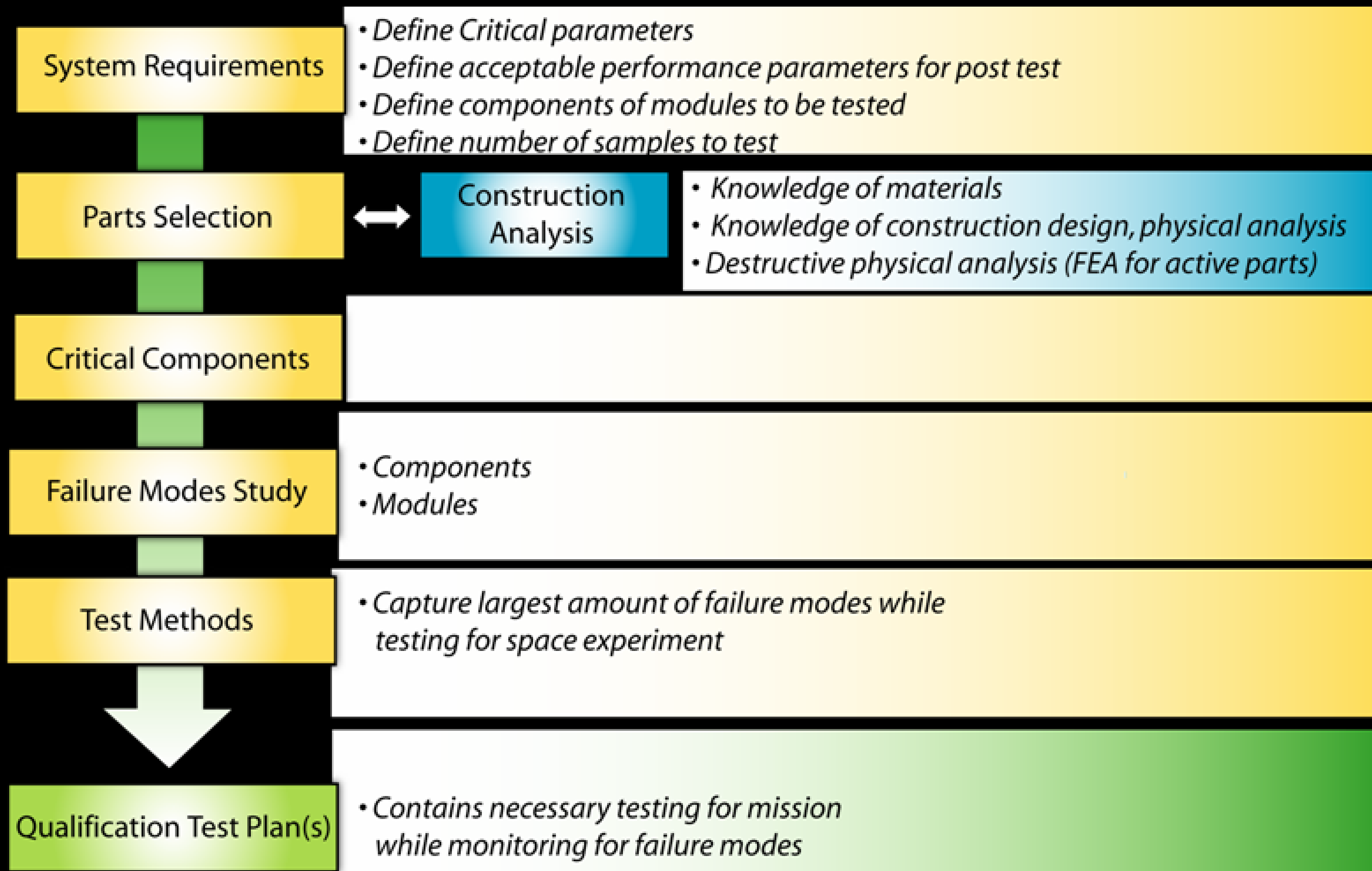
Document Name	CM Document Number
Optical Cable Inspection	562-PHOT-QAD-MSL-FON1482-INSP
Cable Thermal Pre-Cond	562-PHOT-QAD-MSL-THERM-PC
Polymers Degas	562-PHOT-WOA-MSL-BOOTS (Hytrel degas @ Materials)
Mission Survival Radiation Total Dose Testing	562-PHOT-QAD-MSL-RAD (12-day worst-case cobalt60 radiation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

Define "Qualification"

Are you rich or are you poor?

- $$$$= MIL-STD's + Telecordia + NASA Requirements
  - Lifetime Lot buys for COTS parts or anything that will go obsolete.
- $$$ = Telecordia + NASA Requirements
  - Buy critical parts , qualify by Lot.
- $$ = COT Approach for Space Flight (NASA Requirements)
  - Requires careful planning especially with materials selection
  - Lot specific testing
  - Destructive physical analysis necessary early on
  - Radiation testing performed early in selection phase.

COTS Technology Assurance Approach



* *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

COTS For Space Flight "Qualification"

Materials Analysis	• *Outgas testing for anything unknown* • *Take configuration into account*
Vibration Survival and "Shock Test"	• *Use components levels as defined by system requirements* • *Define parameters to monitor during testing*
Thermal Cycling / Aging Test	• *Define which parameters will indicate which failure mode* • *Monitor those parameters during testing*
Radiation Testing	• *Acclerated dose rate* • *Extrapolation model use if possible* • *Worst conditions*
Additional Tests	• *Based on specific mission requirements*
Qualification Assurance Plan	• *Continued reliable performance over life of mission*

* *Photonic Components for Space Systems*, M. Ott, Presentation for Advanced Microelectronics and Photonics for Satellites Conference, 23 June 2004.

Tools You Can Use

NASA Electronic Parts & Packaging Program (NEPP) Radiation Database 2008

http://nepp.nasa.gov

http:// photonics.gsfc.nasa.gov

NEPP Optical Fiber Radiation Database
Commercial Optical Fiber Descriptions
Multimode Optical Fiber Candidates

GSFC

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MULTIMODE FIBER DESCRIPTIONS SUMMARY TABLE

Fiber ID	Manufacturer	Part Number	Fiber Description	Ref#
MM-021002	Heraeus	SSU 1.2 107/00	Step Index; 104/125/250; 0.22na; High OH Low Cl; CCDR 1.2; 40m & 70m	[1]
MM-021003	Heraeus	STU 1.2 237/2000	Step Index; 104/125/250; 0.22na; High OH Low Cl; CCDR 1.2; 40m & 70m	[1]
MM-021004	Mitsubishi Rayon	STR100C-SY	Step Index; 100/150/300; Low OH; 40m & 70m	[1]
MM-021005	FORC	KS-4V	Step Index; 110/125/280; 0.6^2 OH	[1]
MM-022204	Fujikura Ltd.	G-series MM Fiber	F-doped OH free; 200/250; 20m Length	[2]
MM-022205	Mitsubishi	MF Fiber	F-doped OH free; 200/250; 20m Length	[2]
MM-031101	Polymicro	FVP300330370	300/330/370; 0.7m - 1.68m Length	[3]
MM-031102	Polymicro	FIP300330370	300/330/370; 1.68m - 2.06m Length	[3]
MM-031401	Polymicro	FIA200220500	200/220/500; Acrylate; W.L. Gore FON1173; 10m Length	[4]
MM-031402	Polymicro	FIA300330500	300/330/500; Acrylate; W.L.Gore FON1174; 10m Length	[4]
MM-051201	OFS	F14369	Graded Index; Polyimide; Hermetic; 0.20na; 20m Length	[5]
MM-051202	Corning	InfniCol Fiber 50/125	0.20na; Graded-Index; Acrylate; 20m Length	[5]
MM-060204	Nufern	GR50/125-23-HTA	50/125; Graded-Index; <10m Length; Rad-Hard	[6]
MM-060205	Nufern	GR62.5/125-27-HTA	62.5/125; Graded-Index; <10m Length; Rad-Hard	[6]
MM-060206	Nufern	GR100/140-24-HTA	100/140; Graded-Index; <10m Length; Rad-Hard	[6]
MM-060207	OFS	BF04431	62.5/125; Graded-Index; <10m Length; Rad-Hard	[6]
MM-060208	OFS	BF05444	100/140; Graded-Index; <10m Length; Rad-Hard	[6]
MM-061701	Nufern	GR 100/140-24-HTA	12-Fiber 100/140 Graded-Index; 6.35m; Rad-Hard; W.L.Gore FOA 8100/12/1	[7]
MM-071101	ThorLabs	BFL37-200	200/230; Low OH; 50m Length	[8]
MM-071102	ThorLabs	BFH37-200	200/230; High OH; 50m Length	[8]
MM-072101	Polymicro	FIA200220500	200/220/500; Acrylate; 0.22NA; W.L. Gore FON1173 10m Length	[9]
MM-072201	Polymicro	FIA400440580	400/440/500; Acrylate; 0.22NA; W.L. Gore FON1416; 9.5m Length	[10]
MM-090103	Draka	RadHard SMF	DRAKA Elite 50/125/242; 1km length	[11]
MM-090104	Draka	Super RadHard SMF	DRAKA Elite 50/125/242; 1km length	[11]
MM-090201	Nufern	FUD3731	300/330; 0.12NA; W.L. Gore FON1442 PEEK Jacket; 10m Length	[12]

NEPP Optical Fiber Radiation Database
Radiation Effects Summary Multimode Candidates

GSFC
CODE 562 PHOTONICS Group @ GSFC

MULTIMODE FIBER RADIATION EFFECTS SUMMARY TABLE

Fiber ID	λ(nm)	Dose Rate (Gamma)	Total Dose (Gamma)	Temp	Attenuation (dB/m)	Details	[Ref#]
MM-021002	829nm	125 rads/s	1M rads	25°C	0.013	Graph Data	[1]
	829nm	125 rads/s	300 krads	25°C	0.008	Graph Data	[1]
	829nm	125 rads/s	100 krads	25°C	0.0065	Graph Data	[1]
	829nm	125 rads/s	30 krads	25°C	0.005	Graph Data	[1]
MM-021003	829nm	125 rads/s	1M rads	25°C	0.2	Graph Data	[1]
	829nm	125 rads/s	300 krads	25°C	0.25	Graph Data	[1]
	829nm	125 rads/s	100 krads	25°C	0.29	Graph Data	[1]
	829nm	125 rads/s	30 krads	25°C	0.27	Graph Data	[1]
	1310nm	125 rads/s	1M rads	25°C	0.012	Graph Data	[1]
	1310nm	125 rads/s	300 krads	25°C	0.013	Graph Data	[1]
	1310nm	125 rads/s	100 krads	25°C	0.014	Graph Data	[1]
	1310nm	125 rads/s	30 krads	25°C	0.015	Graph Data	[1]
MM-021004	829nm	125 rads/s	1M rads	25°C	0.16	Graph Data	[1]
	829nm	125 rads/s	300 krads	25°C	0.08	Graph Data	[1]
	829nm	125 rads/s	100 krads	25°C	0.045	Graph Data	[1]
	829nm	125 rads/s	30 krads	25°C	0.029	Graph Data	[1]
	1310nm	125 rads/s	1M rads	25°C	0.01	Graph Data	[1]
	1310nm	125 rads/s	300 krads	25°C	0.005	Graph Data	[1]
	1310nm	125 rads/s	100 krads	25°C	0.004	Graph Data	[1]
	1310nm	125 rads/s	30 krads	25°C	0.003	Graph Data	[1]
MM-021005	829nm	125 rads/s	1M rads	25°C	0.65	Graph Data	[1]
	829nm	125 rads/s	300 krads	25°C	0.9	Graph Data	[1]
	829nm	125 rads/s	100 krads	25°C	1.00	Graph Data	[1]
	829nm	125 rads/s	30 krads	25°C	0.96	Graph Data	[1]
	1310nm	125 rads/s	1M rads	25°C	0.027	Graph Data	[1]
	1310nm	125 rads/s	300 krads	25°C	0.028	Graph Data	[1]
	1310nm	125 rads/s	100 krads	25°C	0.026	Graph Data	[1]
	1310nm	125 rads/s	30 krads	25°C	0.025	Graph Data	[1]
MM-022204	600-650nm	333 rads/s	190M rads	25°C	0.9	Reported Data	[2]
MM-022205	600-650nm	333 rads/s	190M rads	25°C	0.25	Reported Data	[2]

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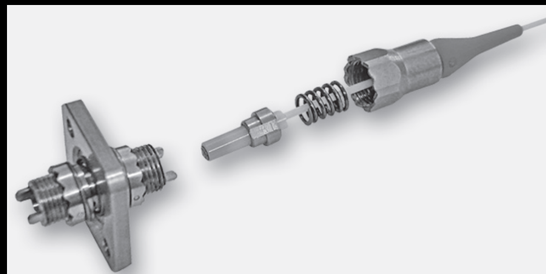
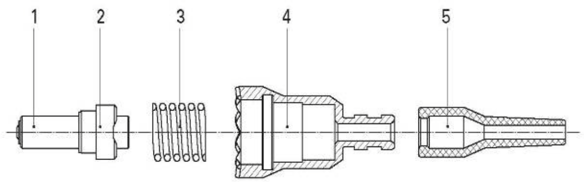
9. X. Jin, M. Ott, F. LaRocca, R. Chuska, S. Schmidt, A. Matuszeski, S. Macmurphy, W. Thomes, R. Switzer, "Space Flight Qualification on a Novel Five-Fiber Array Assembly for the Lunar Orbiter Laser Altimeter (LOLA) at NASA Goddard Space Flight Center", SPIE Optics and Photonics Conference, Photonics Technology for Space Environments II, Vol. 6713, August 2007.
10. M. Ott, X. Jin, F. LaRocca, A. Matuszeski, R. Chuska, S. Macmurphy, "Requirements Validation Testing on the 7 Optical Fiber Array Connector/Cable Assemblies for the Lunar Reconnaissance Orbiter (LRO)", SPIE Optics and Photonics Conference, Photonics Technology for Space Environments II, Vol. 6713, August 2007.

The Diamond Mini-AVIM for Space



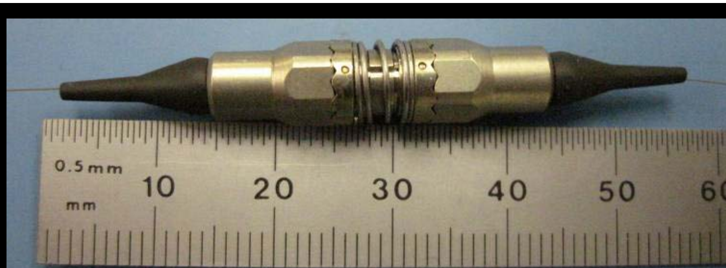
Originally called DMI for Space
Referred to in data set as "Space"

Commercially available terminations or assemblies can be procured @ Diamond



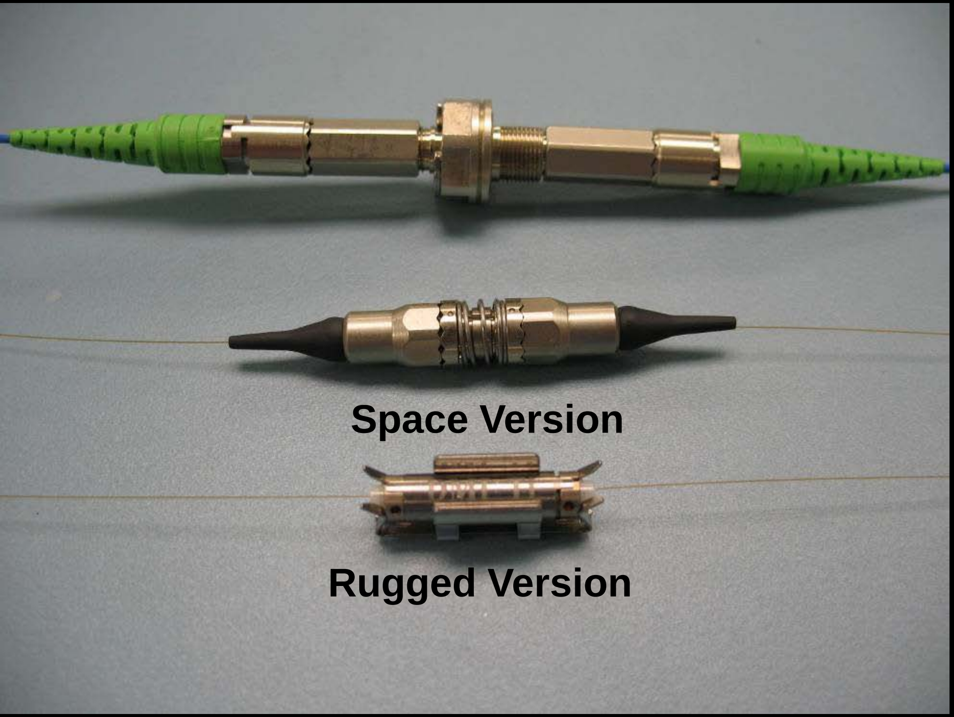
POS.	DESCRIPTION	MATERIAL NAME	MATERIAL NORMS	WEIGHT (gr.)
1	Ferrule	Ceramic-Titanium	ZrO2, UNS R50250	0.27
2	DMI ring	Titanium	UNS R56400	0.09
3	Spring	Stainless steel	1.4310	0.12
4	Outside shell	Titanium	UNS R56400	0.58
5	Vacuum backed boot	Thermoplastic Elastomer TCP-ET	Hytrel 8068[1]	0.06
			Total	**1.12**

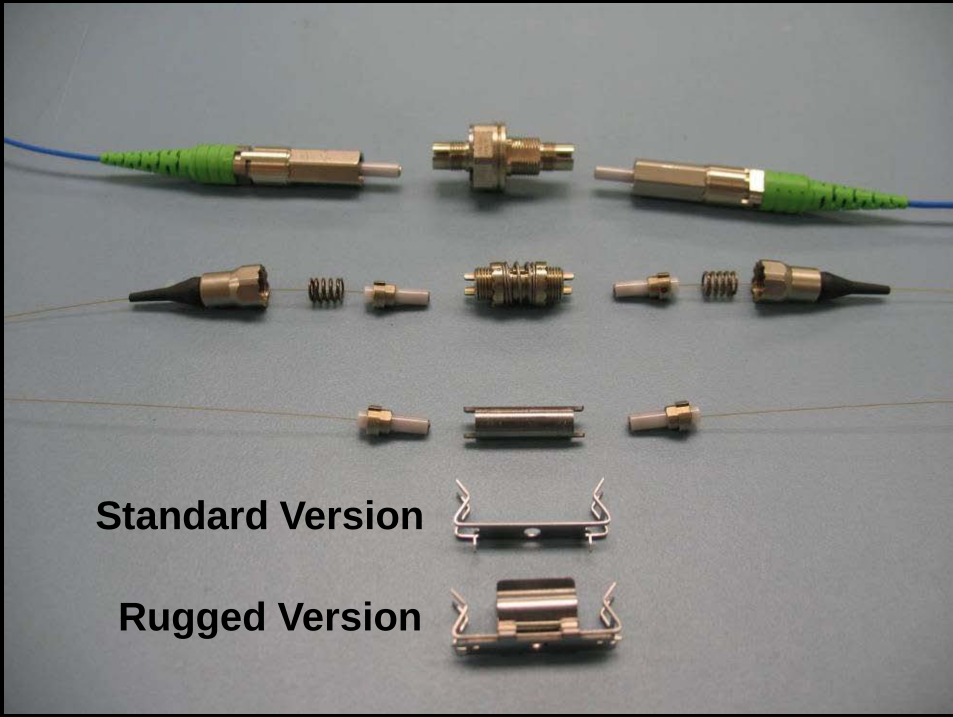
[1] Vacuum baked, 24h at 110°C to 125°C and 10^{-3} Torr



Diamond AVIM vs. Diamond Mini AVIM and DMI Clip – Visual Comparison

AVIM w/ over 10 years of Flight Heritage is now available in a miniaturized version based on the Diamond DMI design





NASA Flight & Test Heritage of the Diamond AVIM

Project	Dev	Launch	Connectors	Description	Details
Geoscience Laser Altimeter System (GLAS) on ICESAT	1998	2001	AVIM Standard Single Mode / Multi Mode / Flat Polish	Gore Flexlite SM & MM 2 Km of SM	Custom drill in ferrule, tungsten carbide shell ferrules
Mercury Laser Altimeter (MLA) MESSENGER	2001	2004	AVIM Standard, Flat Polish	330 um MM Flexlite	Custom drill in ferrule, tungsten carbide shell ferrules
Shuttle Return to Flight NEPTEC Laser Heat Tile Sensor	2003	2005	AVIM standard SM APC & SM	BICC OC1008, one sided terminations.	Standard pilz ferrule, ceramic shell
Lunar Orbiter Laser Altimeter on Lunar Recon Orbiter	2007	2009	AVIM array connector, 303 SS ferrule drill @ GSFC	SS larger PM AVIM for 5 220 um fibers side one, fan out standard side two, Flexlite	Custom drill 220 um on fan out side, with standard AVIM tungsten carbide shell ferrules
Laser Ranging on Lunar Recon Orbiter	2007	2009	AVIM Array connector, 416 SS ferrule flower drill @ Diamond	SS larger PM AVIM for 7 440 um fibers, large custom cable	Both sides array flower pattern. Gimbal, cold, to -55 C.
Mars Science Lab, Chemcam	2008	TBD	AVIM standard custom drill ferrule for 330 um	Flexlite	Gimbal, cold, hot to 110 C
Express Logistics Carrier on ISS	2008	Nov-2009	AVIM standard custom drill for 140 um	Space Station cable & Flexlite	Pilz ceramic shell ferrules
NASA GSFC evaluation of Mini AVIM & DMI	2008	none	Bare fiber for thermal and vibration testing.		
James Webb Space Telescope	2008	GSE	FC & AVIM titanium ferrules.	No cable, cryogenic application.	Multiple sizes, multiple materials

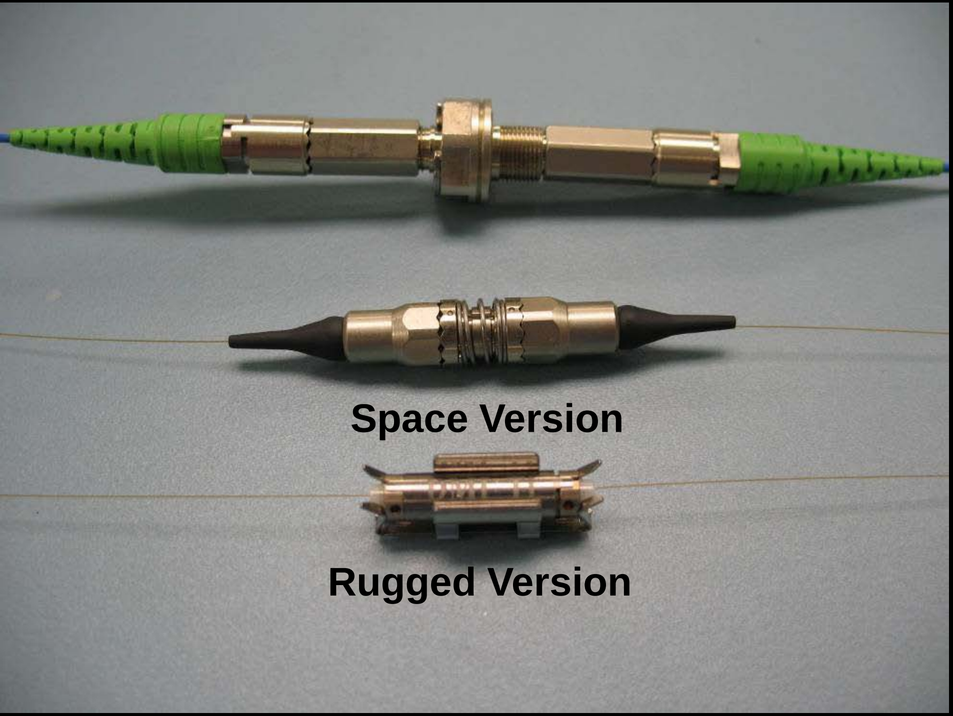
Small Form Factor Interconnects Applications

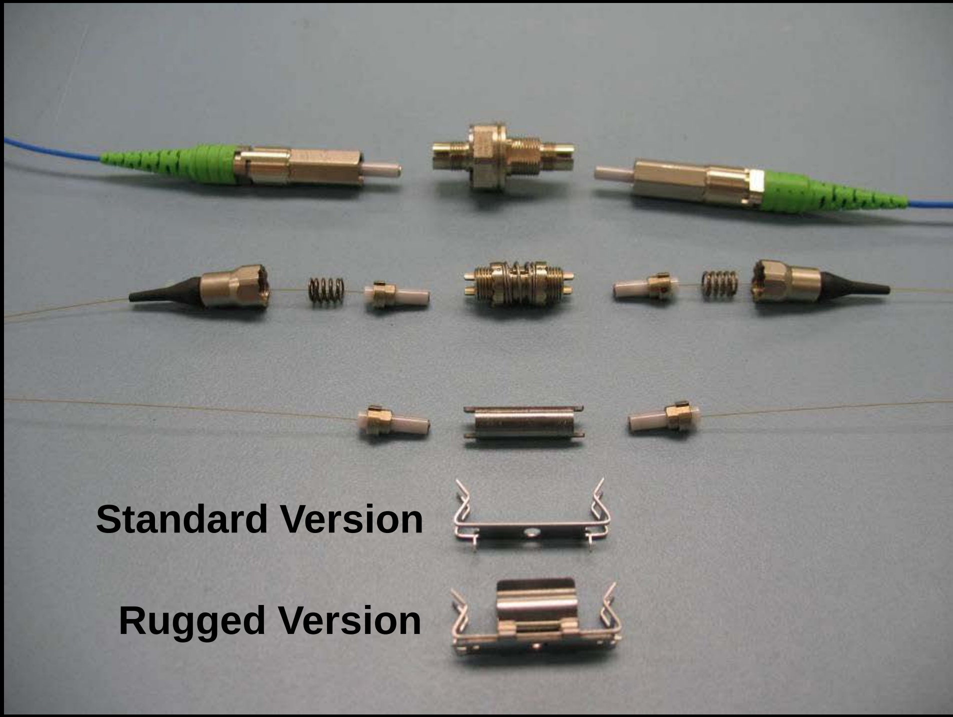
- Diamond AVIM is best rugged connector but too big for newer applications that require small and light-weight too.
- Intra-satellite Comm - In-box optical fiber communication systems/ Transceivers.
- Science Instruments - On board calibration systems for instrumentation.
- Telescopes and spectroscopy applications in small spaces.
- Ranging and LIDAR instrumentation.
- Transmitters and Receiver systems
- Fiber lasers for laser communications
- Detectors near board electronics where there is no room available for large connections.

Component Evaluations for Small Form Factor Applications

Diamond Mini AVIM Multimode Characterization Study the following tests were conducted in 2009:

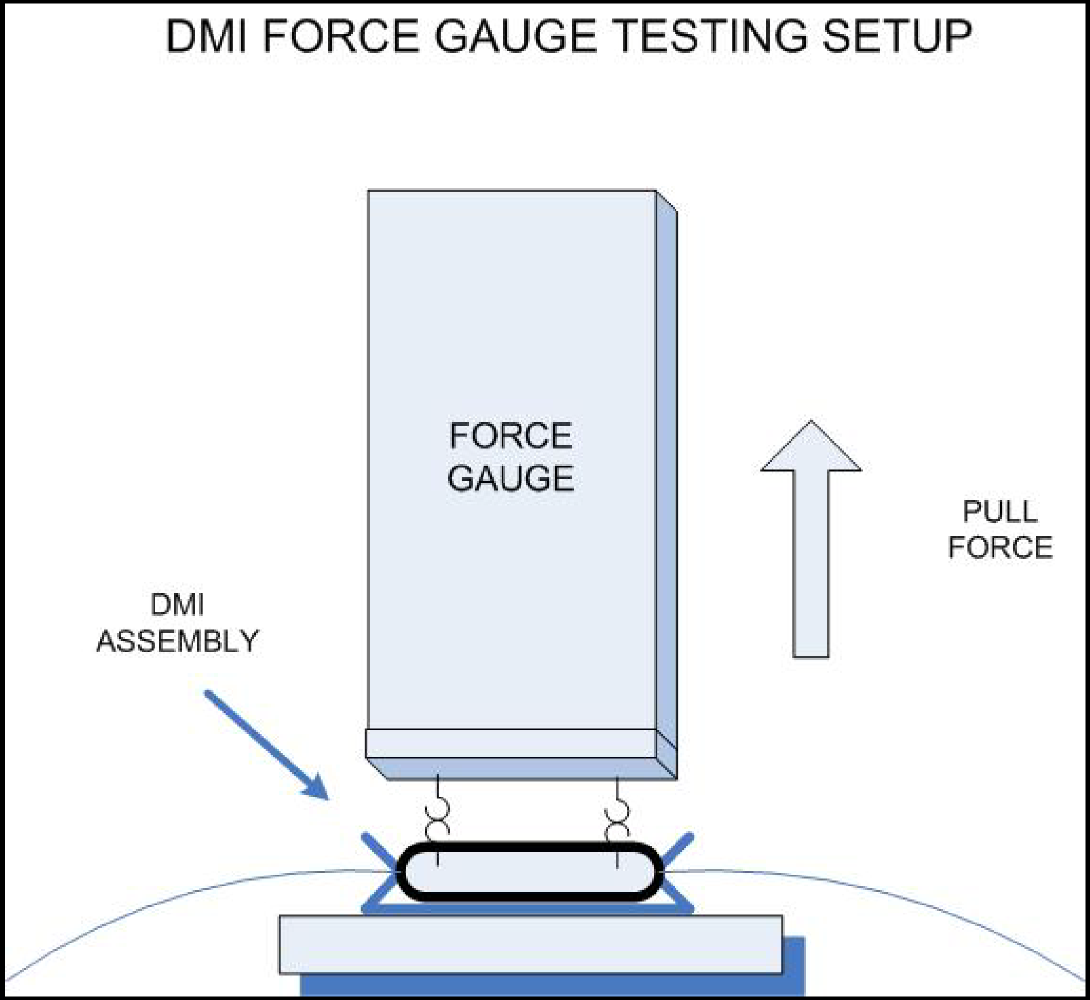
Pull Force Data
Thermal Testing
Vibration Testing





Step 1: Evaluate prototype for feasibility in space environments and make recommendations

Pull Test Data



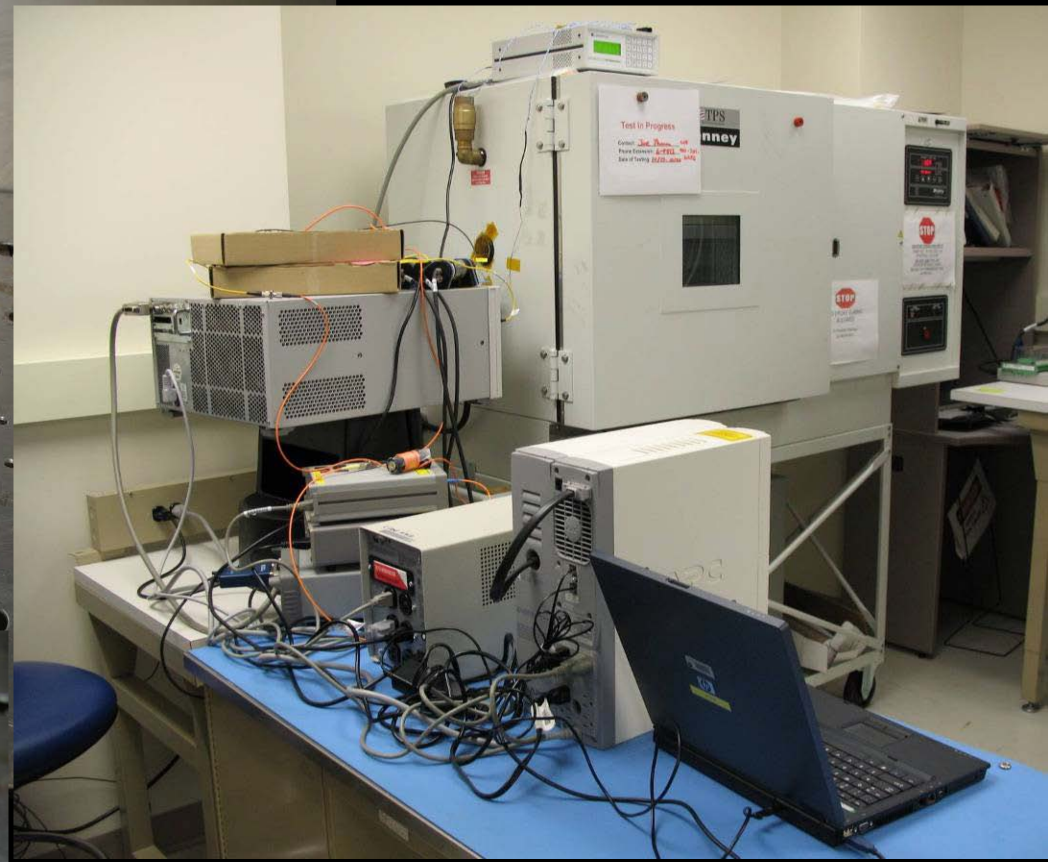
20 trials conducted on each type of spring clip for retention.
Monitored for when connector released from retention spring clip.

Average Stainless Steel Non Rugged= 6.6 N
Average BeCu Non Rugged = 16.6 N

Average Stainless Steel Rugged= 30.9 N
Average BeCu Rugged = 44.4 N

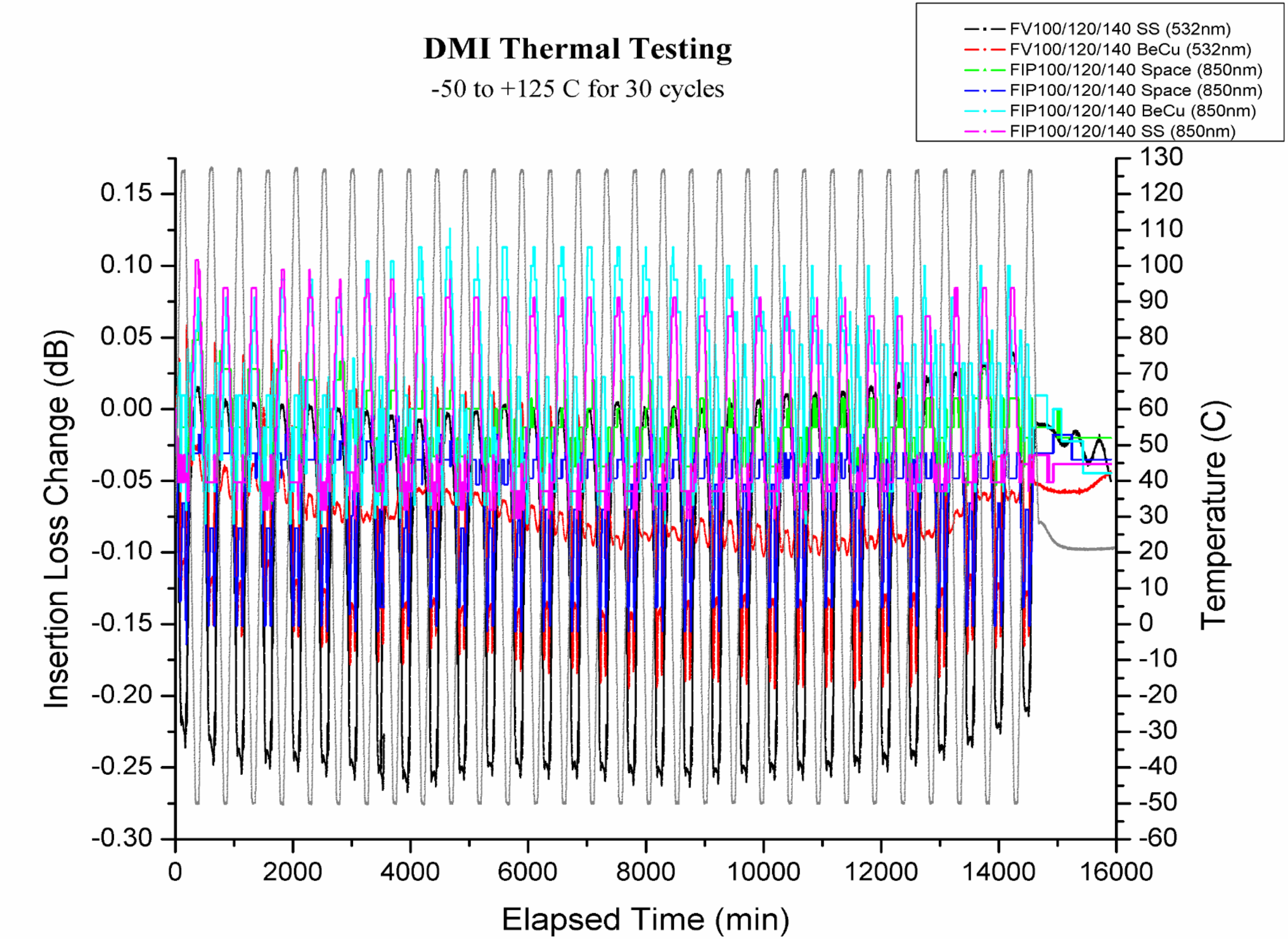
This was for the DMI w/ Clip not the Mini AVIM

Thermal Validation Testing DMI (Mini AVIM)



Fiber w/ Connectors only

-50°C to +125°C Cycling
In-situ Monitoring for Insertion Loss changes based on Termination/Connector, no cable.
30 Cycles
Tested Workmanship & Performance



Ruggedized and Space Version

Vibration Validation Testing

Four Tests Conducted with insitu monitoring: 10 grms, 14 grms, 20 grms, 35 grms
Random Vibration conducted for 3 mins per axis, for each of x, y, z axis configuration

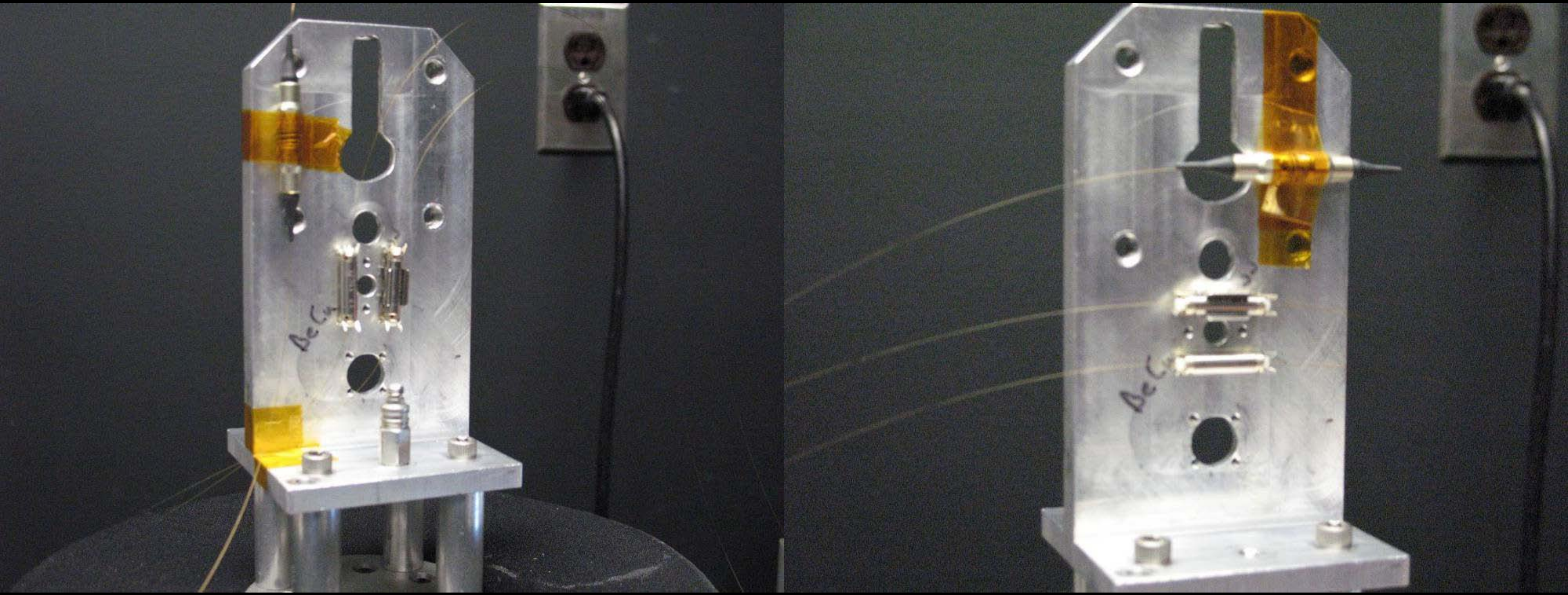
Frequency (Hz)	Level
20	0.013 g^2/Hz
20-50	+6 dB/octave
50-800	0.08 g^2/Hz
800-2000	-6 dB/octave
2000	0.013 g^2/Hz
Overall	9.8 grms

Frequency (Hz)	Level
20	0.026 g^2/Hz
20-50	+6 dB/octave
50-800	0.16 g^2/Hz
800-2000	-6 dB/octave
2000	0.026 g^2/Hz
Overall	14.1 grms

Frequency (Hz)	Level
20	0.052 g^2/Hz
20-50	+6 dB/octave
50-800	0.32 g^2/Hz
800-2000	-6 dB/octave
2000	0.052 g^2/Hz
Overall	20.0 grms

Frequency (Hz)	Level
20	0.156 g^2/Hz
20-50	+6 dB/octave
50-800	0.96 g^2/Hz
800-2000	-6 dB/octave
2000	0.156 g^2/Hz
Overall	34.63 grms

Vibration Validation Testing

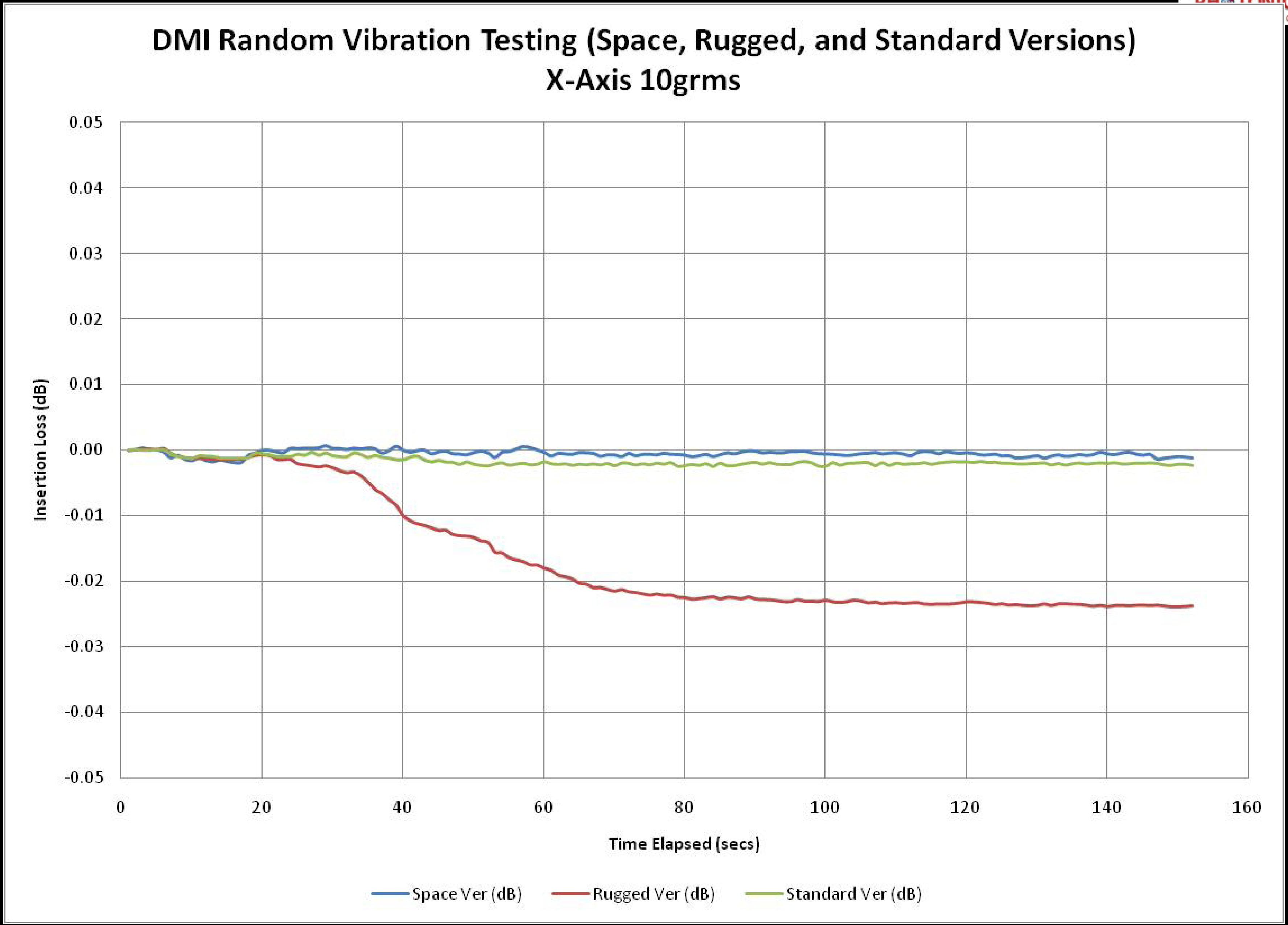


X & Y configurations for the DMI connectors during Random vibration

Vibration Validation Testing Results for the DMI & Mini AVIM for 10 grms

GSFC

CODE 562 PHOTONICS @ GSFC



Vibration Testing Summary

DMI SPACE VERSION			
Axis	**grms Level**	**Max IL**	**Avg IL**
X	10grms	-4.8E-04	6.6E-04
Y	10grms	-8.3E-05	2.2E-04
Z	10grms	1.2E-03	1.9E-03
X	14.1grms	-1.6E-03	9.4E-05
Y	14.1grms	6.6E-04	1.3E-03
Z	14.1grms	-3.1E-02	1.4E-03
X	20grms	-1.1E-02	0.0E+00
Y	20grms	-1.1E-02	2.1E-03
Z	20grms	-2.0E-02	3.5E-04
X	34.6grms	6.5E-03	1.1E-02
Y	34.6grms	2.4E-03	6.3E-03
Z	34.6grms	3.0E-02	3.6E-02

DMI RUGGED VERSION			
Axis	**grms Level**	**Max IL**	**Avg IL**
X	10grms	-1.6E-02	2.9E-04
Y	10grms	4.2E-04	9.8E-04
Z	10grms	1.2E-05	3.4E-04
X	14.1grms	-1.3E-02	1.7E-05
Y	14.1grms	-2.4E-03	0.0E+00
Z	14.1grms	-2.3E-03	1.8E-04
X	20grms	-9.9E-03	0.0E+00
Y	20grms	-5.2E-03	2.3E-04
Z	20grms	1.2E-03	4.7E-03
X	34.6grms	4.1E-03	7.6E-03
Y	34.6grms	6.7E-03	1.0E-02
Z	34.6grms	3.6E-03	4.9E-03

DMI STANDARD VERSION			
Axis	**grms Level**	**Max IL**	**Avg IL**
X	10grms	-1.7E-03	7.6E-05
Y	10grms	-3.6E-04	2.5E-04
Z	10grms	1.5E-03	2.4E-03
X	14.1grms	-2.5E-03	1.3E-04
Y	14.1grms	3.7E-04	1.2E-03
Z	14.1grms	-4.1E-03	8.0E-05
X	20grms	8.6E-02	1.0E-01
Y	20grms	-8.5E-03	7.4E-05
Z	20grms	3.2E-03	6.8E-03
X	34.6grms	2.7E-03	6.8E-03
Y	34.6grms	-5.9E-04	6.0E-03
Z	34.6grms	-1.2E-02	1.4E-04

Data shows less than 0.05 dB Insertion Loss change or not above noise floor.

Evaluation Testing on the Single Mode Mini-AVIM 2010

Preconditioning of Flexlite -30 to +130 C, 60 cycles, dwells @ extremes 60 min hot, 30 min cold.
Termination: Diamond / Photonics Group Termination Process – 6 Assemblies with SM fiber
Performance Validation: End face validation, interferometry verification, insertion loss validation test.
Thermal Workmanship Test: 10 cycles

Testing : 1) Random Vibration Testing – same as was performed for mulltimode w/ insitu monitoring 20 and 35 grms – 3 min/axis, 3 axis configuration – 3 mated pairs.
2) Thermal Cycling 60 to 100 Cycles, -55 to + 125 C w/ insitu monitoring. – 3 mated pairs.
3) Cryogenic Testing to 100 K (-173 C) for 48 hours w/ insitu monitoring, -- 3 mated pairs.

Cable Thermal Preconditioning – June 2010
Completion of Assemblies – July 2010
Thermal Workmanship – July 2010
Vibration Testing – Aug 2010
Thermal / Cryo Testing – Aug 2010
Report – Sept - 2010

Diamond DMI & Mini AVIM Small Form Factor Conclusions

1) Thermal Cycling resulted in less than 0.25 dB max change in Insertion Loss for all types during cycling – nominal as compared to the AVIM for MM fiber.

2) Vibration Testing results conclusion; no significant changes – nominal as compared to AVIM.

3) Met with engineers at Diamond Switzerland to discuss uses and changes.

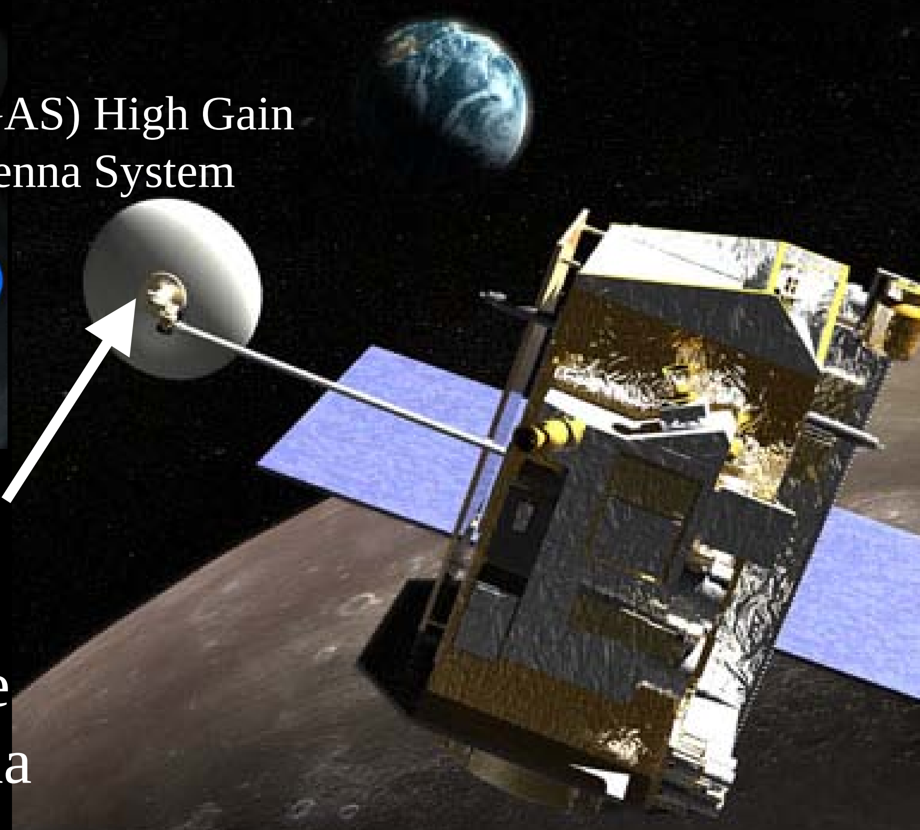
5) ESA and NASA conducting evaluations on the Mini-AVIM for Single Mode space flight applications currently.

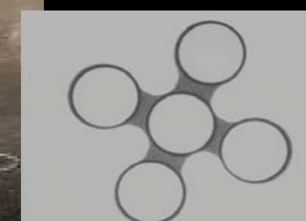
6) @ GSFC, assemblies being built with SMF-28 in W.L. Gore Flexlite, evaluation to be complete by end of 2010.

Current Project Updates

The Lunar Reconnaissance Orbiter; The Laser Ranging Mission and the Lunar Orbiter Laser Altimeter

(HGAS) High Gain Antenna System

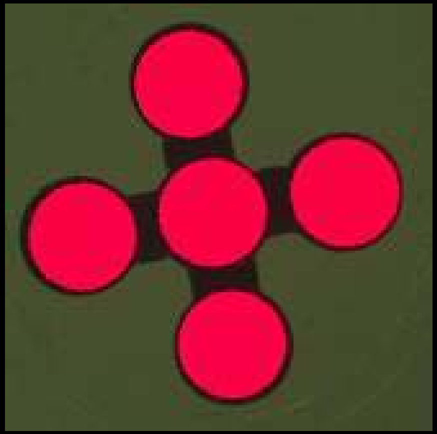




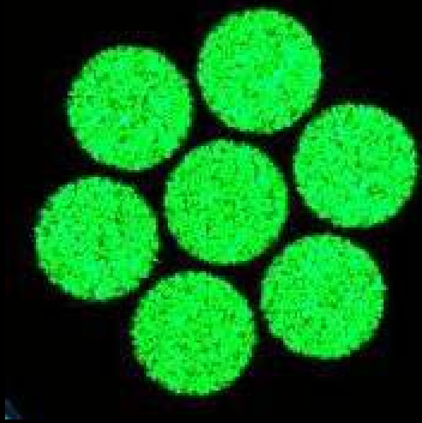
Receiver Telescope mounted on antenna and a fiber array to route signal from HGAS to LOLA

Lunar Orbiter Laser Altimeter (LOLA)

NASA GSFC Fiber Optic Array Assemblies for the Lunar Reconnaissance Orbiter



Array Side End Face Picture at 200X magnification

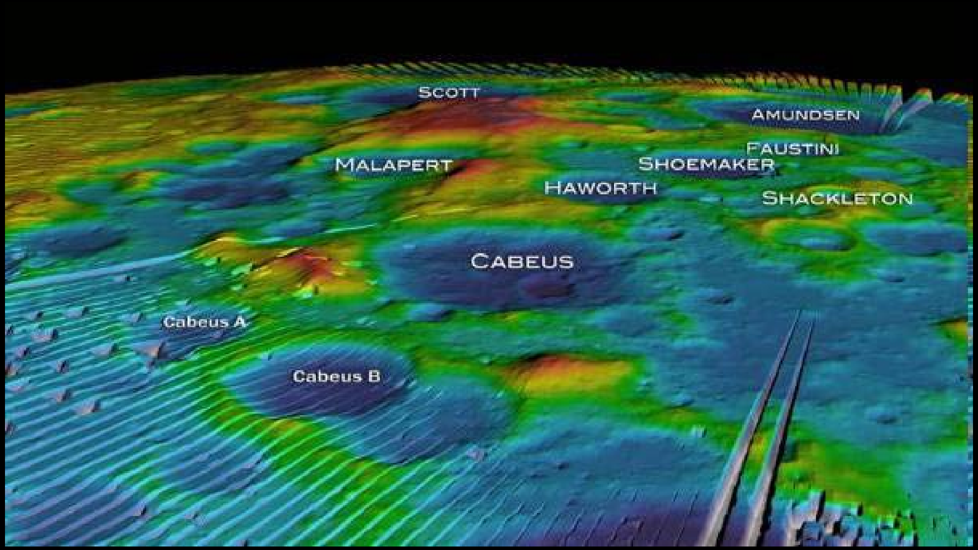


End Face Picture of both assembly ends at 200X magnification

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 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.

http://www.foxnews.com/slideshow/scitech/2009/09/23/water-moon?slide=9

NASA

Mars Science Lab, Chem Cam
AVIM connectors – Flexlite Cable

GSFC

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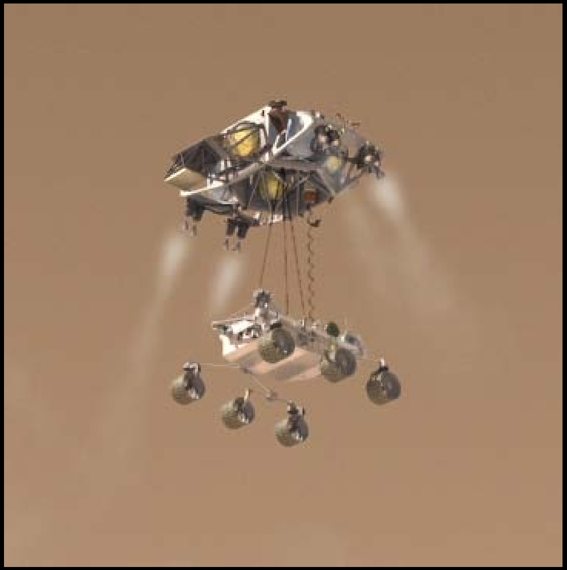
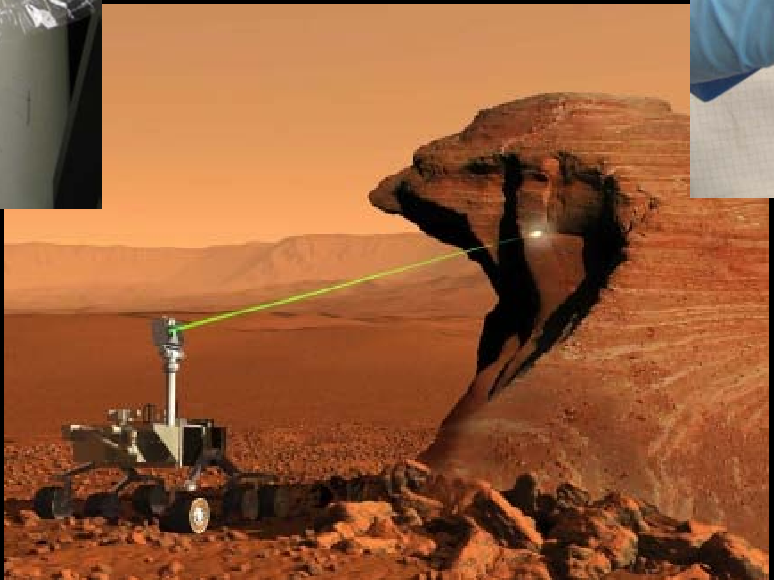
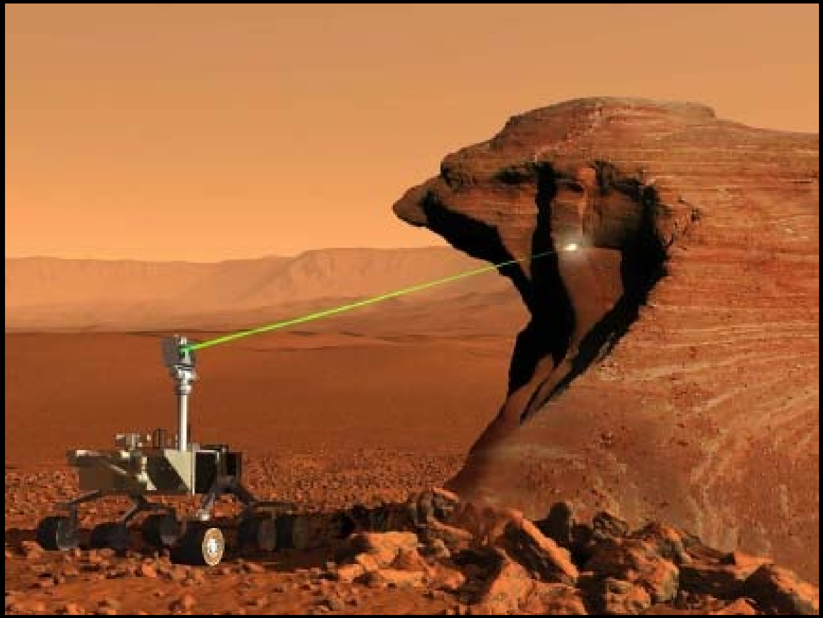


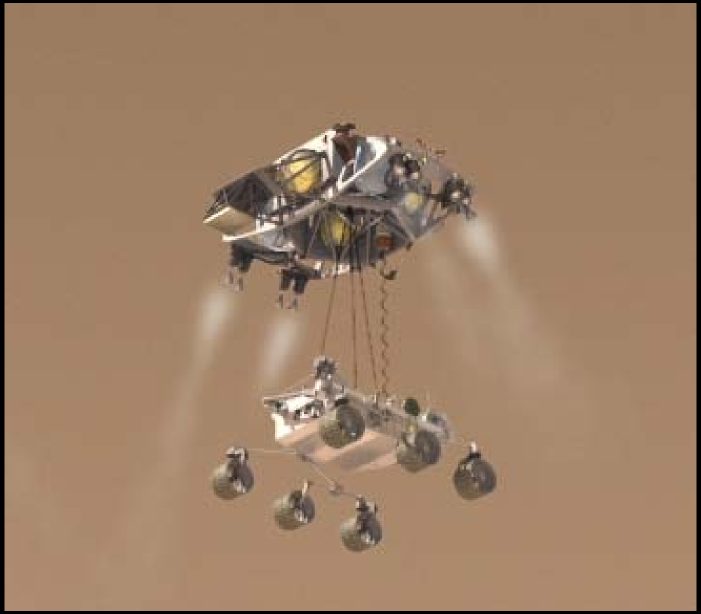


Mars Science Lab – ChemCam Optical Assemblies, Launch delayed.

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.**

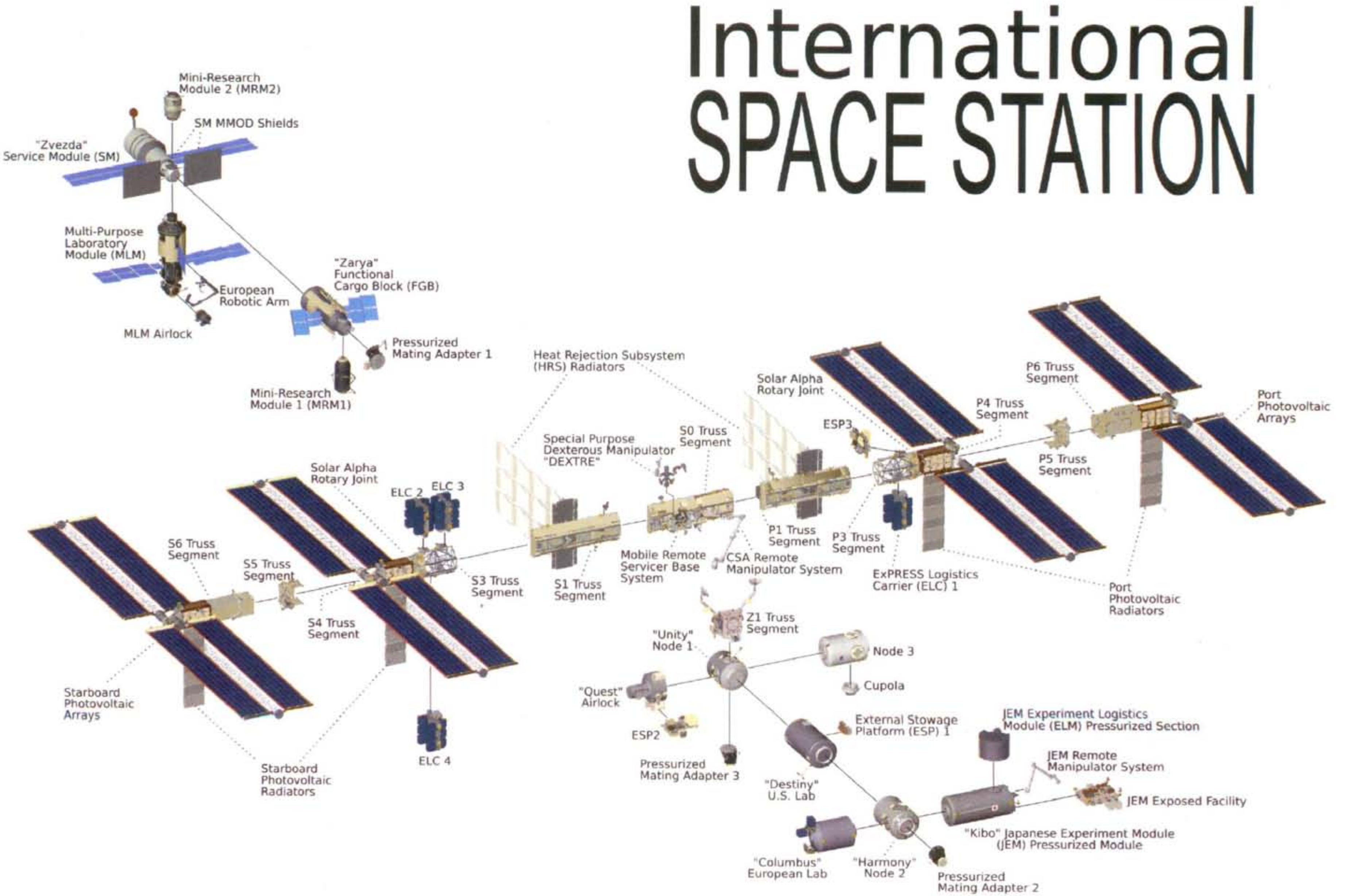




Express Logistics Carrier (ELC modules) “Smart Warehouse for Station”

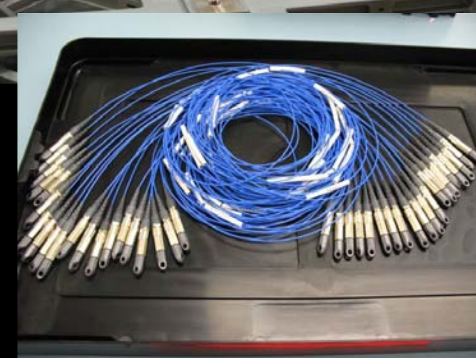
GSFC

CODE 562



Express Logistics Carrier for ISS; Communications System Assemblies

GSFC
CODE 562 PHOTONICS Group @ GSFC

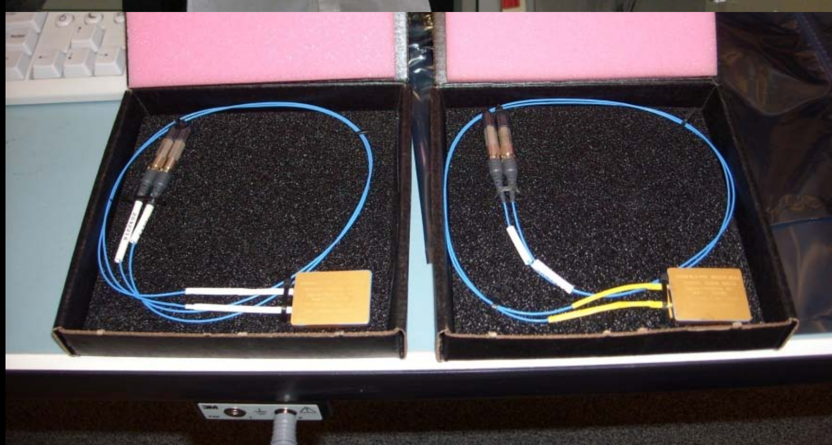


GSFC Photonics Group –
Flight Control Unit Transceiver Assemblies
(Space Photonics) SPI- FCU Transceivers
GSFC Photonics Group - Harnessing

Subsystem Components

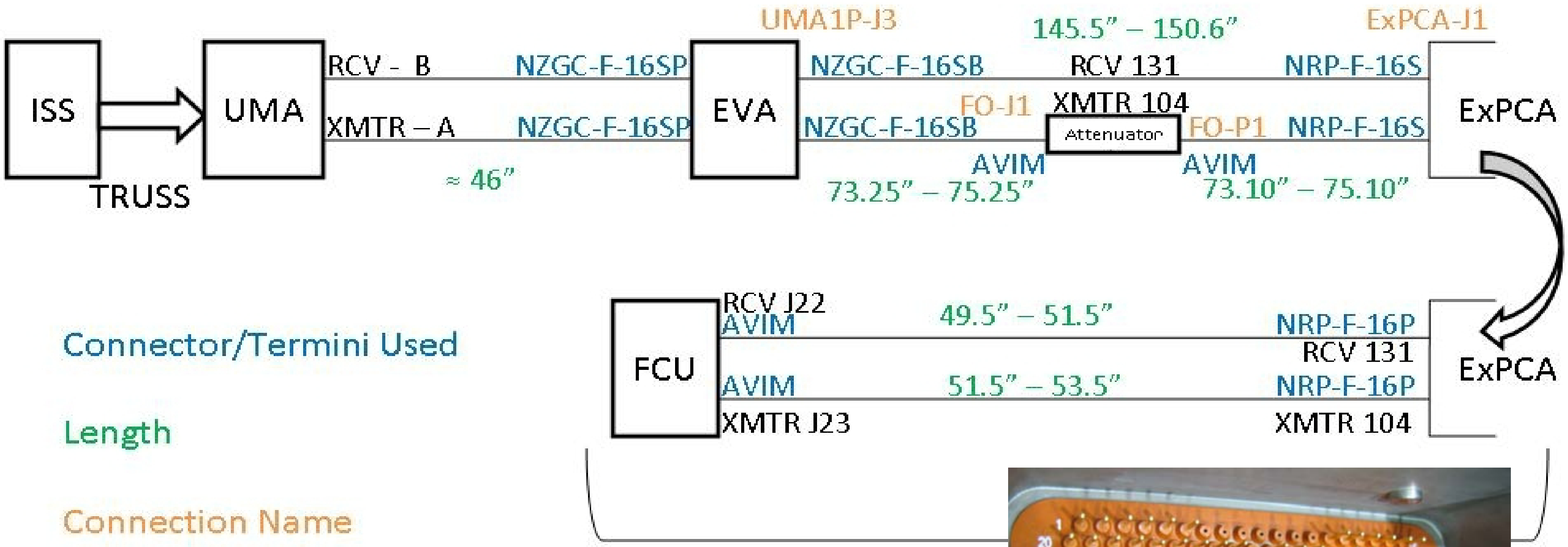
Component	Manufacturer	Part Number/ Identifer
Transceivers for FCU	Space Photonics	HMP1-TRX
Transceiver Interconnection	Diamond	AVIM
Transceiver Optical Fiber	Nufern	FUD-2940
Transceiver Cable	W.L Gore	Flexlite, simplex FON1435
ExPCA Interconnection	Sabritec	SSQ22680
ExPCA Termini	ITT Canon	SSQ21636-NRP-F-16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

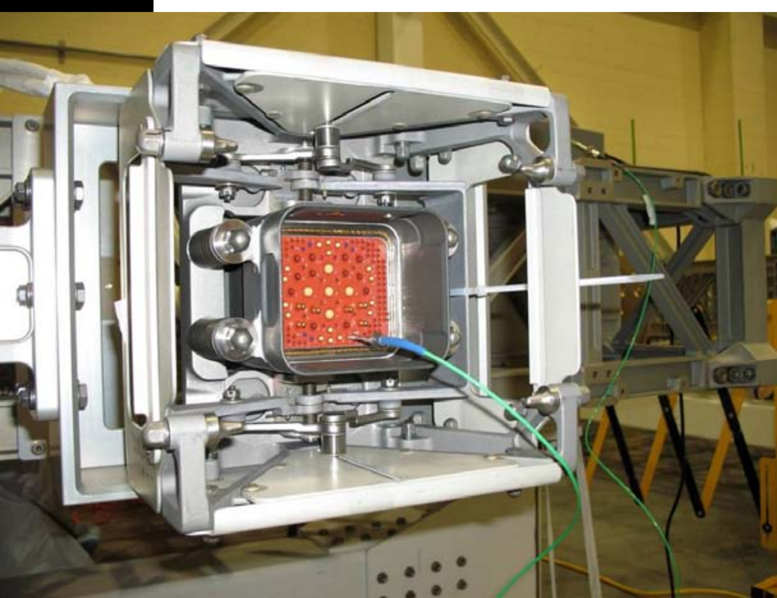
Express Logistics Carrier, Connection to ISS AVIM connectors – Flexlite Cable

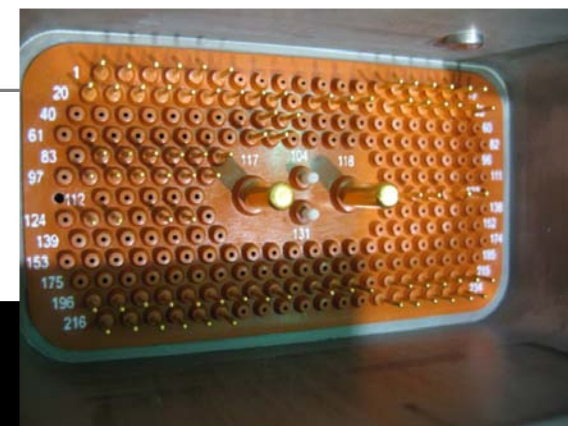


Fiber Optic Flight Assemblies for Space Photonics Transceivers

Harnessing Diagram for Express Logistics Carrier on ISS







ExPCA Connector

Integration of the ELC assemblies at KSC International Space Station Facility

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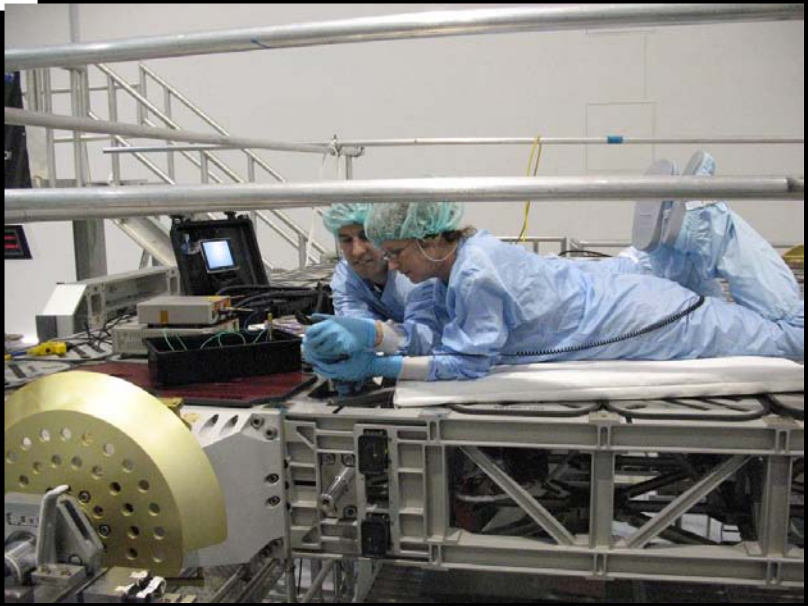
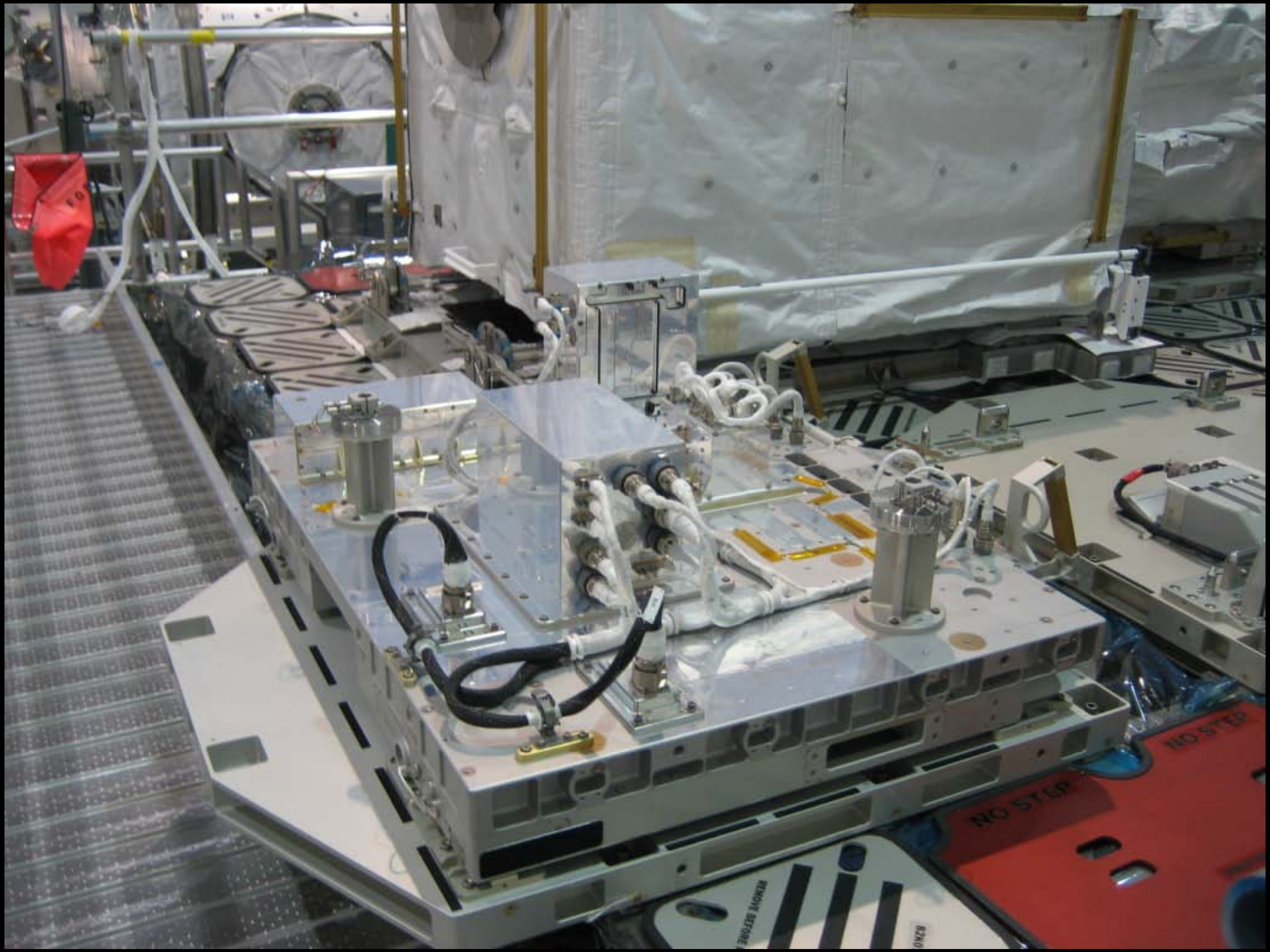


Last assemblies to integrate into the harnessing were the optical fiber assemblies, reason = risk mitigation.
Schedule constraints led to integration at the
International Space Station Processing Facility at Kennedy Space Center.
Lesson Learned= Integrate sooner.

ELC Cargo on ISS



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.

ELC Launches to ISS on STS-129

Engineers inspect one of the ExPRESS Logistics Carriers in the small clean room at NASA's Goddard Space Flight Center

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

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.

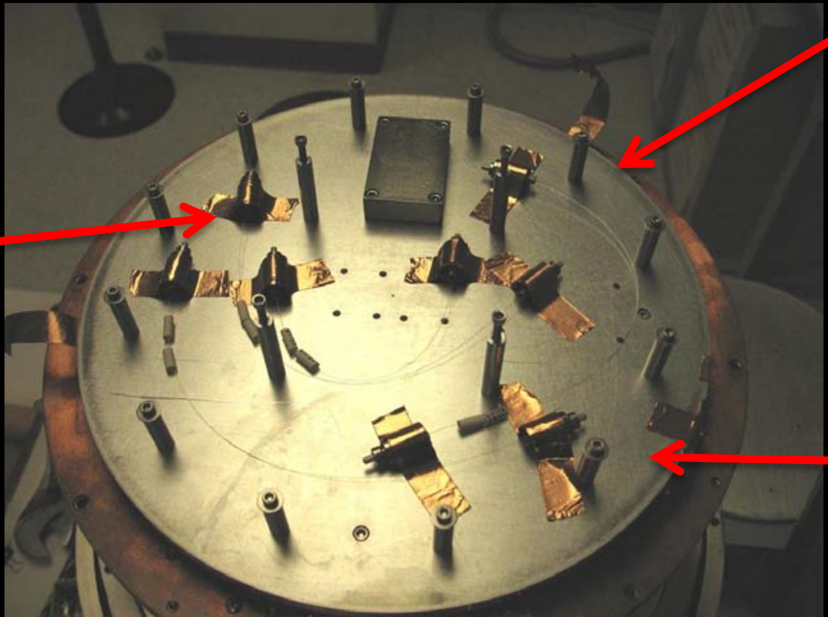
James Web Space Telescope Optical Simulator (OSIM)

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 assembies are:
Side A: Ceramic/Titanium ferrules, Side B: Diamond FC

Fiber Optic Terminations



Temperature Controlled Heat Plate

Chamber Cold Plate

Some Lessons Learned

- Know your failure modes or higher an expert to do it for you.
  - ✓ Materials analysis now or later, you decide.
  - ✓ Vendors get information from outgassing database – its 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.

Thank you for the invitation!

For more information

http://photonics.gsfc.nasa.gov