ISS Fiber Optic Link Development Lessons Learned Journey

BOEING

David Gill

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ISS Journey to Utilize Fiber Optic Technology

President Regan Announces Permanent Manned Space Vision

1984

SSF Phase A SSF (Architectural) Studies

1986

SSF Phase B (Requirements Development)

1989

SSF Phase C/D (DDT&E)

1993

President Clinton Announces to Change SSF to an International Space Station

1997

Space Shuttle Experiment (FOFE) Launched with ISS FO Components in an experimental configuration

1998

Node 1 Launched with 54 FO Links on 5 W/H with 8 Environmental Interconnects and 2 Hermetic Interconnects

FO Cable "Bubble" Investigation and Risk Mitigation Activities

Timeline Not to Scale

2005

1985 LDEF was launched in Space Shuttle

1989 NASA/Industry Team Define Up Front Requirements for SSQ FO Components

1994 ISS FO Procurements Initiated

1995 ISS FO Cable was Qualified

1996 ISS FO Environmental Interconnects were Qualified

1997 ISS FO Hermetic Interconnects were Qualified

1999 Failures were investigated that lead to the "Rocket Engine" Defect

2000 ISS Accepted FO Risk Mitigation Analysis and Plans

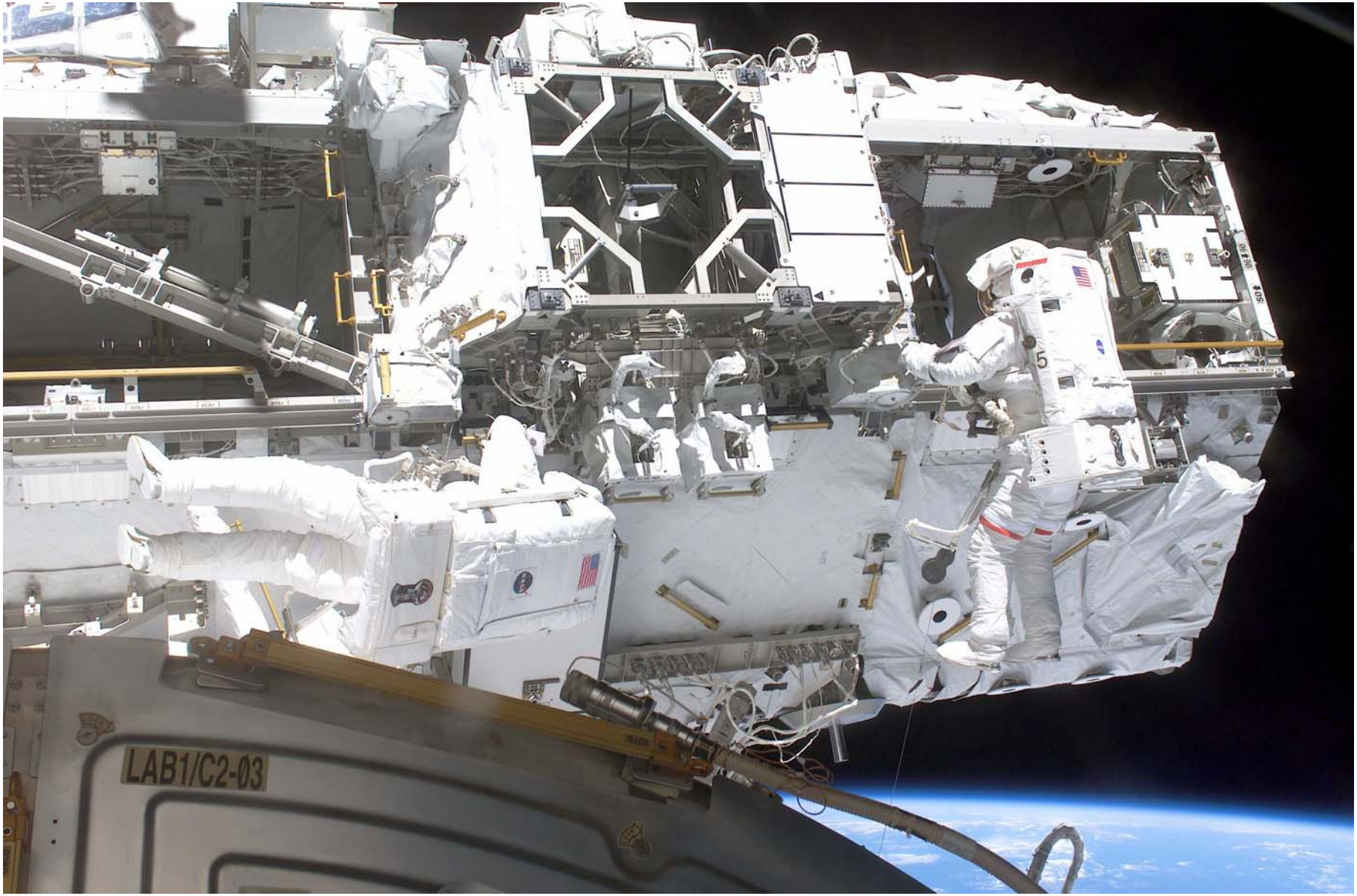
2001 ISS FO Maintenance Kit Launched on 6A

ISS was morphed from Space Station Freedom – Fiber Optics Technology was pushed into Vehicle Systems

FO Components Embedded in ISS Systems

- Caution and Warning System
  - Internal Audio
- Payload Data System
  - Internal and External Ethernet
- Video System
  - Internal and External
- Used in All American ISS Elements except the Primary Power System Elements
- Used on ESA and NASDA Elements
- Russian Elements did not use FO

FO Components Are Used on an S0 Element



Fiber Optic Components / Qualified Performance

SSQ Spec	SSQ P/N	SSQ Approved Supplier	Description	Thermal / Environment	Mechanical Environment	Optical Perf. Req's
21635 **21636** **21637**	NZGC NRP NU	Amphenol ITT Cannon G&H Technologies	Circular Connectors Rack and Panel Connectors Umbilical Connectors	• Thermal Shock 25 cycles -100°C to +150°C • Thermal Life **21635:** -115°C & 150°C for 500 hours **21636:** 150°C for 500 hrs **21637:** -115°C & 150°C for 250 hours • Differential Temp Δ150°C Low end -66°C max.	Durability 500 mate cycles NATC 1000 mate cycles NZGL Maintenance Aging 10 insert-removal cycles Salt Spray **21635 & 21637:** 5% for 96 hrs **21636:** 5% for 48 hrs 21637: Random Vibration **21635 &** 3.5 min/axis, 1.0 G^2Hz. **21636:** 3 min./axis, 43.7 G RMS **21637:** 7 min/axis, 1.0G^2Hz	Ambient Loss Substitution Loss < 0.4 dB change Induced Loss < 0.3 dB End of Life Loss Average = 0.85 dB Std. Dev. = 0.28

SSQ's Specifications were developed to define the requirements Common Components for ISS.

Fiber Optic W/H Component / Qualified Performance

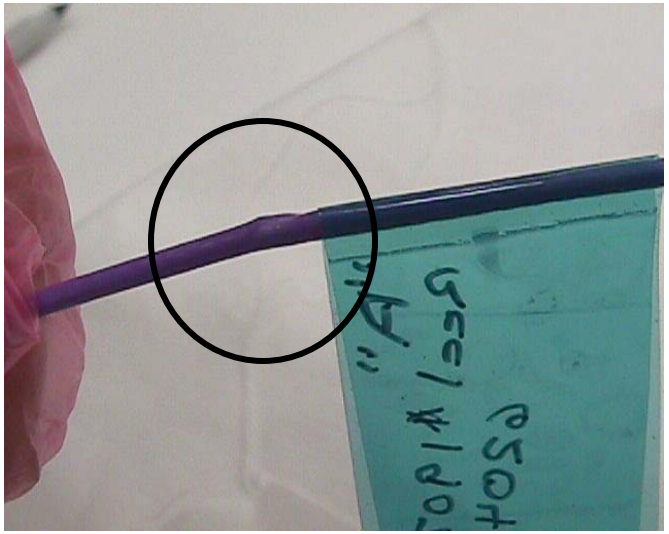
SSQ Spec	SSQ P/N	SSQ Approved Supplier	Description	Thermal / Environment	Mechanical Environment	Optical Perf. Req's
21635 **21636** **21637**	NZGC NRP NU	Amphenol ITT Cannon G&H Technologies	Circular Connectors Rack and Panel Connectors Umbilical Connectors	• <u>Humidity</u> **21635:** 240 Hours at 95% **21636:** 10 cy of 16 hours, 1 cy. = 40°C @ 94% RH and 40°C @ 85% RH **21637:** N/A for Fiber Optics • <u>Storage</u> **21635:** -100°C to +120°C at 10^{-5} torr **21636 & 21637** -115°C to 150°C	<u>Mechanical Shock</u> **21635 & 21637:** 3 per axis, 75G, 11 millisecond **21636:** 3 axis, 30G, 11 millisecond <u>Mating Forces (max)</u> **21635:** Shell<25, < 25 lbs.; Shell 25L to 37, < 25 lbs. **21636:** Size 1, 53 lbs. Size 2, 96 lbs. Size 4, 192 lbs. Size 6, 288 lbs. Size 8, 384 lbs. **21637:** 300 lbs.	

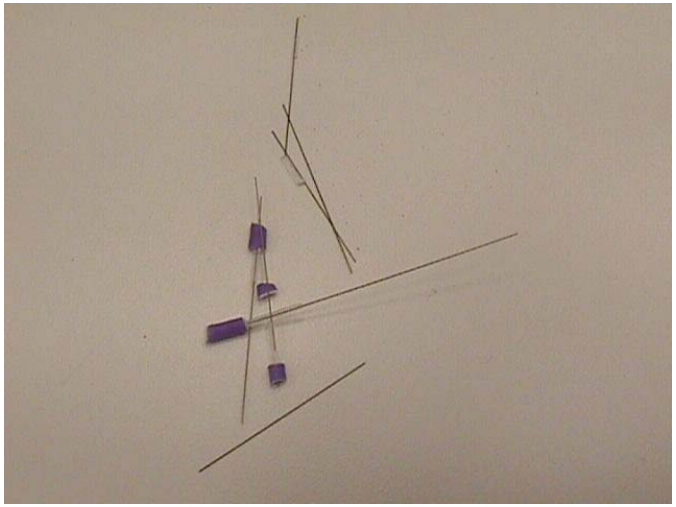
Fiber Optic W/H Component / Qualified Performance

SSQ Spec	SSQ P/N	SSQ Approved Supplier	Description	Thermal / Environment	Mechanical Environment	Optical Perf. Req's
21654	NFOC	Brand Rex		• Fungus – none • Odor < 2.5 rating • Toxicity NHB 8060.1 • Vacuum Stability <1% mass loss, $1X10^{-6}$ torr @ 125°C • Survival Life -135°C & +157°C @ $1X10^{-6}$ torr • Flammability 30% O_2 70% N_2 @ 10 PSI, self-extinguishing • Thermal Shock 25 cycles,-100°C to 150°C per MIL-STD 202 Method 107 • Radiation Resistance 118 Krads @ 0.1 Rad/sec	• Stippability – - Jacket by hand - Fiber coating > 2.5 KG • Cyclic Flexing 2000 cy • Crush 22.6 KG for 60 sec. • Cable Bend 1.25"R • Cable Weight 9KG/Km • Jacket Shrinkage 0.4%	Induced Loss < 0.3 dB Substitution Loss < 0.3 dB End of Life 6 dB/Km

ISS Fiber Optic Cable Lessons Learned

- Design Requirements
  - Fiber Glass Selection
    - Multimode
    - Radiation Hardened
    - Carbon Coated
    - Polyimide Coating
  - Jacket Design and Construction
    - Semi-loose Tube Construction
    - Strength Member
    - Jacket
- Acceptance Requirements
  - Dimensional Controls on Fiber/Coatings
  - Zero Defects on Coatings
  - Cable Visual Inspection
  - Optical Loss Testing
  - Packaging
- Qualification Requirements
  - Quantity of cable tested
  - Quality of the testing
- Supplier Management





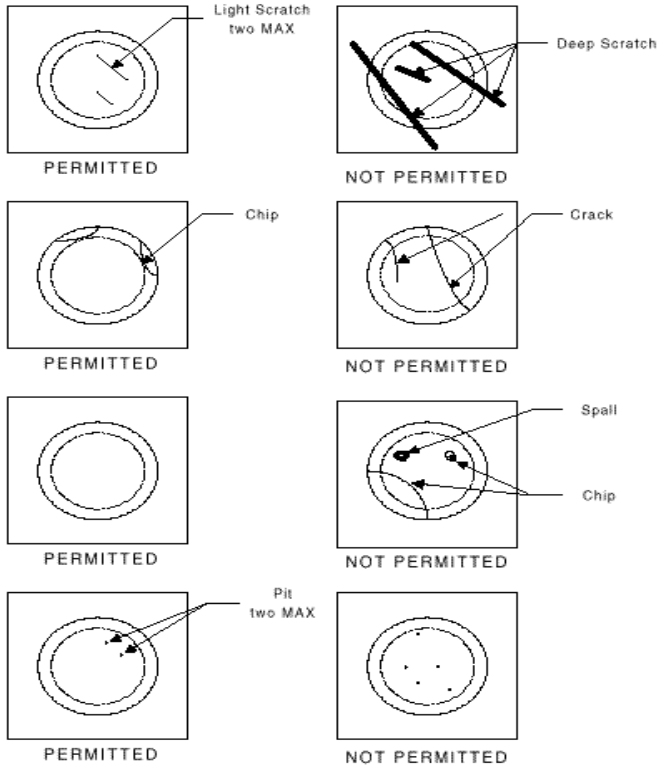
SSQ 21654 FO Cable was Qualified Twice

Example of a Non-conformance Closure Post "Bubble" Alert

- **DISCREPANCY 05**
- ********** ENTER DEFECT DESCRIPTION BELOW: **********
- 14 REELS OF FIBER OPTIC CABLE WAS [illegible] TESTED PER PROCEDURE
- 1T80265 "C" WITH THE FOLLOWING RESULTS:
- REEL # GOOD PCS. FT. DEFECT PCS. FT
- 190764 4 135.44 3 3
- 190836 5 182.76 6 7
- 100501 0 0 SCRAP REEL TOTAL = 175.32
- 100472 11 349.12 12 17.5
- 190837 5 442 4 4
- 190757 0 0 SCRAP REEL TOTAL = 320.56
- 100454 20 532.3 25 39.3
- 190759 0 0 SCRAP REEL TOTAL = 518.88
- 190747 8 778.44 7 7
- 190751 38 1257.44 47 68.5
- 190859 2 208.60 1 1
- 190749 0 0 SCRAP REEL TOTAL = 1198.96
- NOTE: TWO REELS # 190835 (308.52 FT) & # 190752 (863.32 FT) HAVE
- ZERO DEFECTS AND ARE COMPLETE AND ACCEPTABLE
- E.M. THOMSON A033310 A3-436 26NOV01

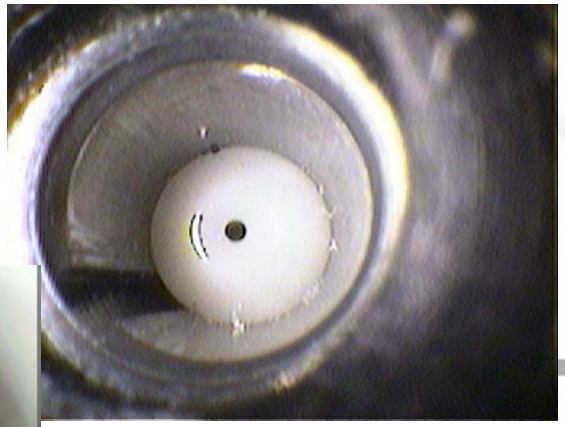
ISS Fiber Optic Interconnects Lessons Learned

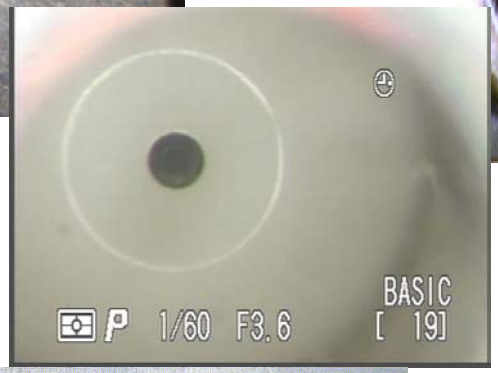
- Environmental Sealed Connector Design Requirements
  - Termini Materials
  - Tolerance Stacks different than Traditional Environmental Connectors with copper
  - Termini
    - Terminations
      - Cure Materials
      - Cure Profiles
      - Concave vs. PC Polish
      - Full fill vs end fill
      - Inspection and Verification
    - Insertion and Removal
    - Optical Testing
  - Number of Insert Configurations
  - Mating Forces and Torques
  - Backshells
  - Mixed Media Types
- Acceptance Requirements
  - Visual Inspections
  - Optical Loss Test
- Qualification Requirements
  - Quantity of configurations tested
  - Quality of the testing
- Supplier Management

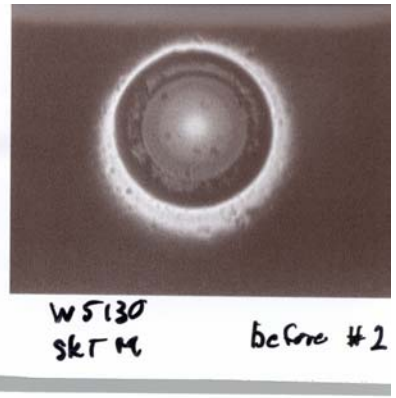


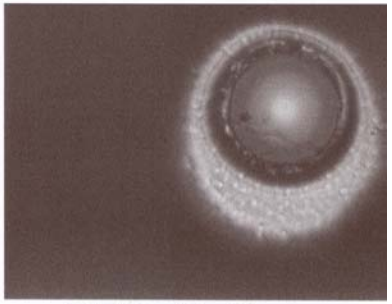
SSQ 21635, 21636 and 21637 Connectors included FO Capabilities

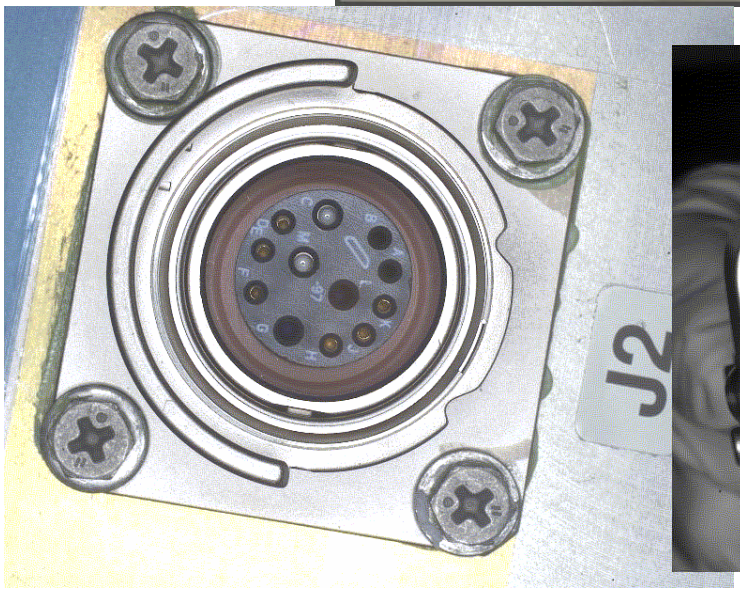
FO Termini and NZGL Environmental Connector Inserts









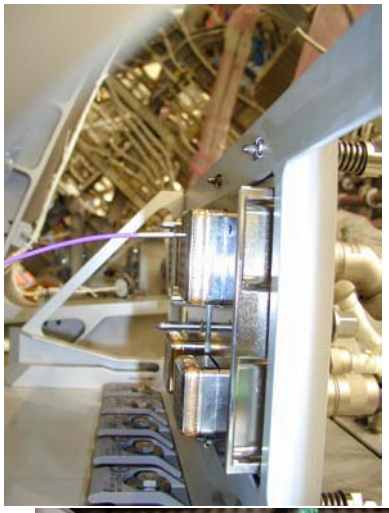


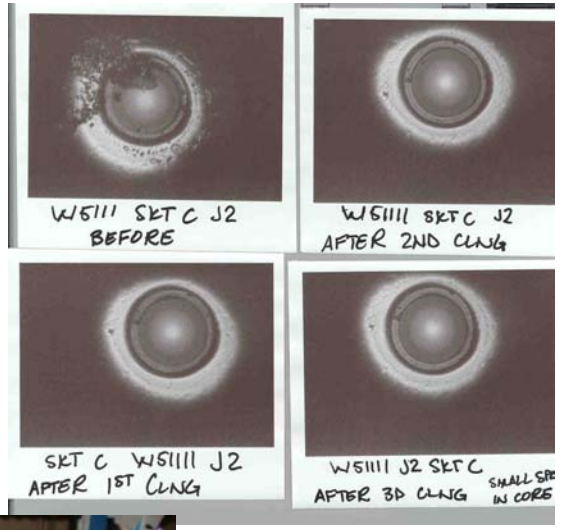
ISS Fiber Optic Interconnects Lessons Learned

- Hermetic Sealed Connector Design Requirements
  - Several Insert/Shell Size Configurations
  - Dimensions of small parts
  - Termini Materials and Seals & Processes
  - Full Fill vs End Fill
  - Inspection and Verification
  - Production Rework of Termini
- Acceptance Requirements
  - Verification of Polish Quality
  - Verification by Test
- Qualification Requirements
  - Quantity of configurations tested
  - Quality of the testing
- Supplier Management

Only SSQ 21635 included Capabilities with Hermetic Sealed FO Termini

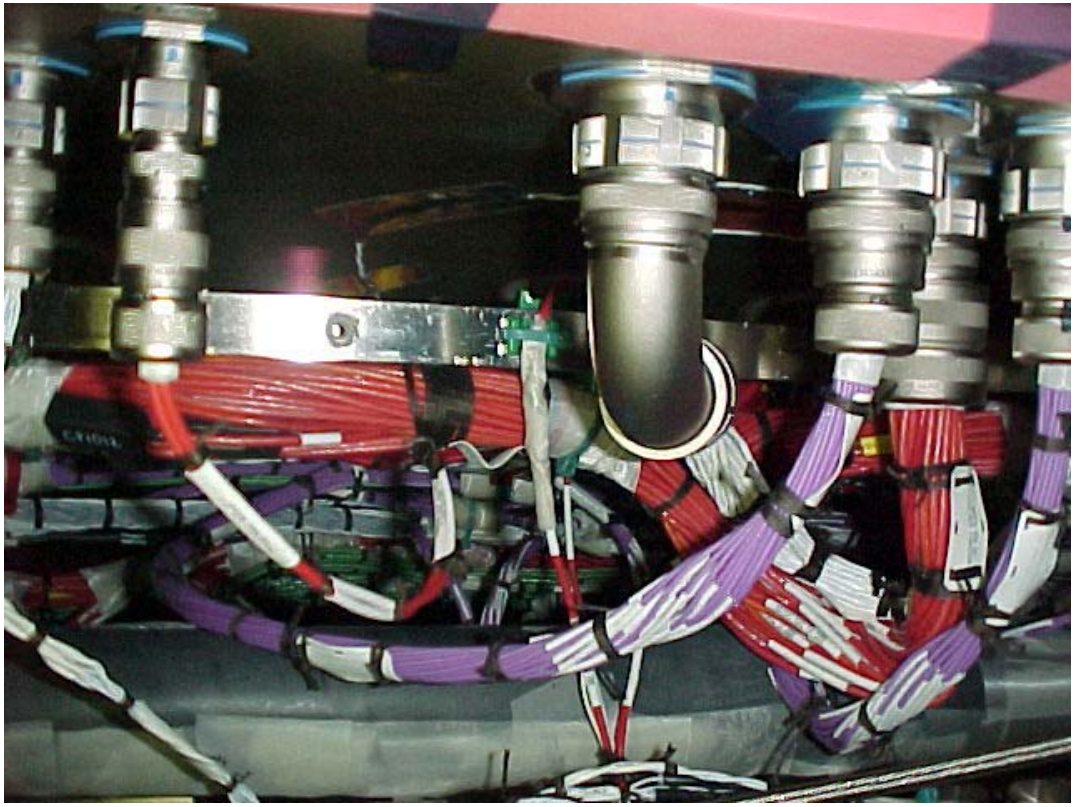
- Design Requirements
  - Bend Radii
  - Clamping
- Acceptance Requirements
  - Visuals
  - Testing
    - Post Installation
    - Functional Performance in System

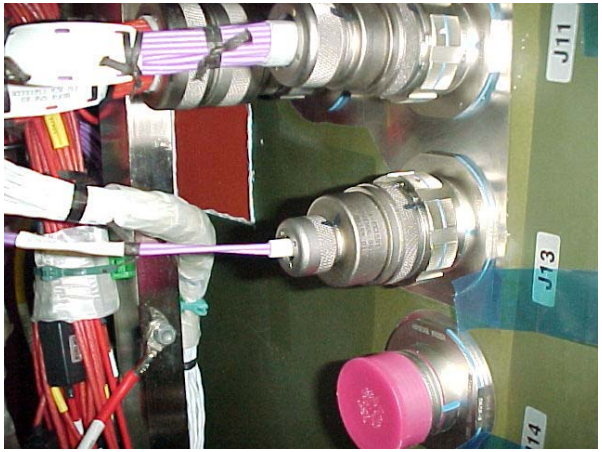


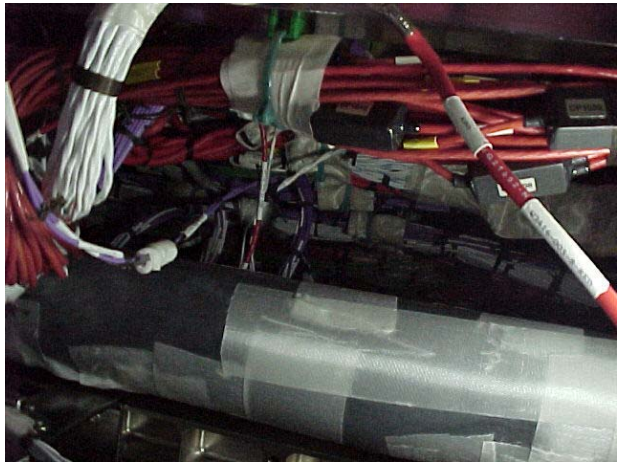


Fiber Optics Were Embedded throughout ISS Elements

FO W/H Installed in US Lab





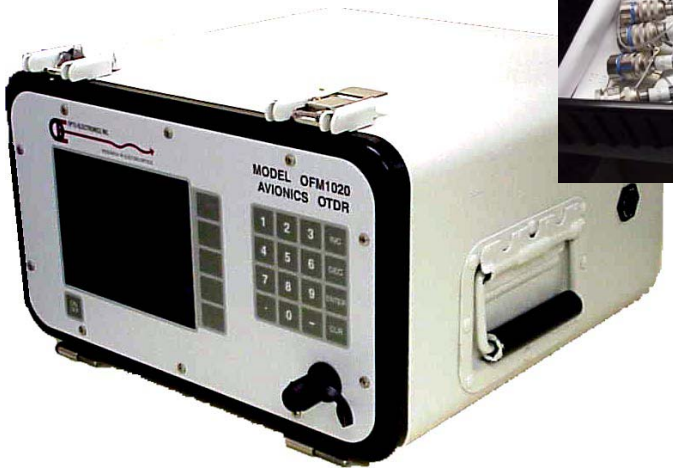


ISS Fiber Maintenance Kits

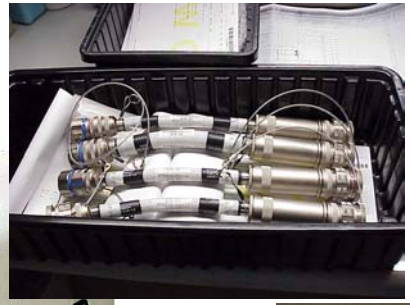
- All Fiber Maintenance Equipment is planned to be flown in 5 different kits/assemblies:
  - Optical Time Domain Reflectometer (OTDR) – 1F92564-1
  - Reel Test Softpack Assembly – 1F92761-1
    - Softpacks
    - FO Test Adapter Assembly (Patch Panel)
    - OTDR to Test Adapter Assembly patch cable
    - OTDR Power Cable (to 28VDC source)
    - Visual Fault Finder (low power HeNe laser)
    - ST/SSQ Cleaning Kits
  - Link Segment Softpack Assembly – 1F92703-1
    - Softpacks
    - Fiber Replacement Links (quantity 36 links in 12 configurations)
    - Backshell Removal Tool
    - Backshell Plyers
    - Fiber Terminis Inseration/Extraction Tools (10)
    - Tie Wraps (100)
  - Test Adapter Softpack Assemblies – 1F92676-X:
    - Softpack Assemblies (quantity 8) –1, -501, -503, -505, -507, -509, -511, -513
    - Test adapters (quantity 15) grouped at next assembly (softpack) in logical groups
  - EVA PDGF Contingency Wire Harness Assembly – 1F92665-1

FO Tool Kit Development – Primary Fault Isolation Tools

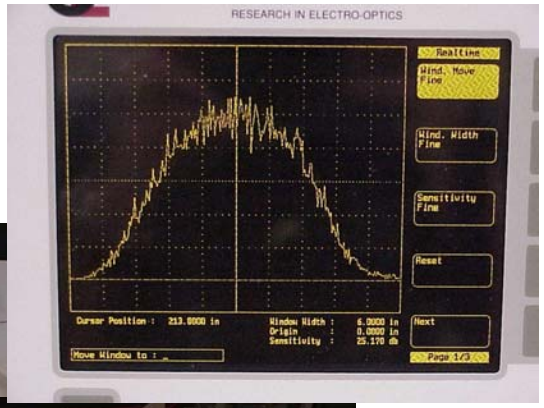
HB Avionics/Electrical Systems (AES)



Optical Time Domain Reflectometer (OTDR)



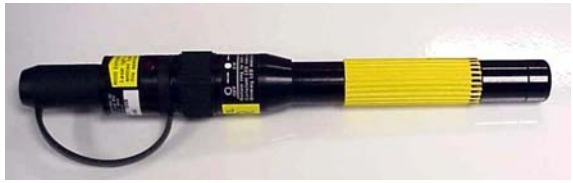
OTDR Signature of an SSQ Mate I/F



Flight Test Adapters
(15 different in 8 differentSoftpack Assemblies))

OTDR/Reel Patch Cable (QTY 3)

Reel Assembly acts as breakout box with 37 termini test capability



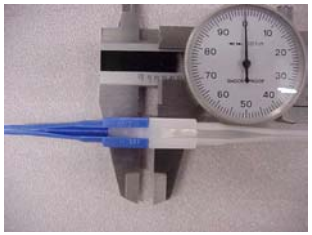
Visual Fault Finder (VFF)

FO Tool Kit Development – Primary Contingency Tools

HB Avionics/Electrical Systems (AES)

Backshell Holding Tool 2

Backshell Holding Tool 1



Insertion/Extraction Tools (QTY 10)

Terminated Flight Links (QTY 36 in 12 Configurations stored
In four diffent low level softpacks)

Multi-purpose EVA PDGF Contingency Cable

FO Tool Kit Development

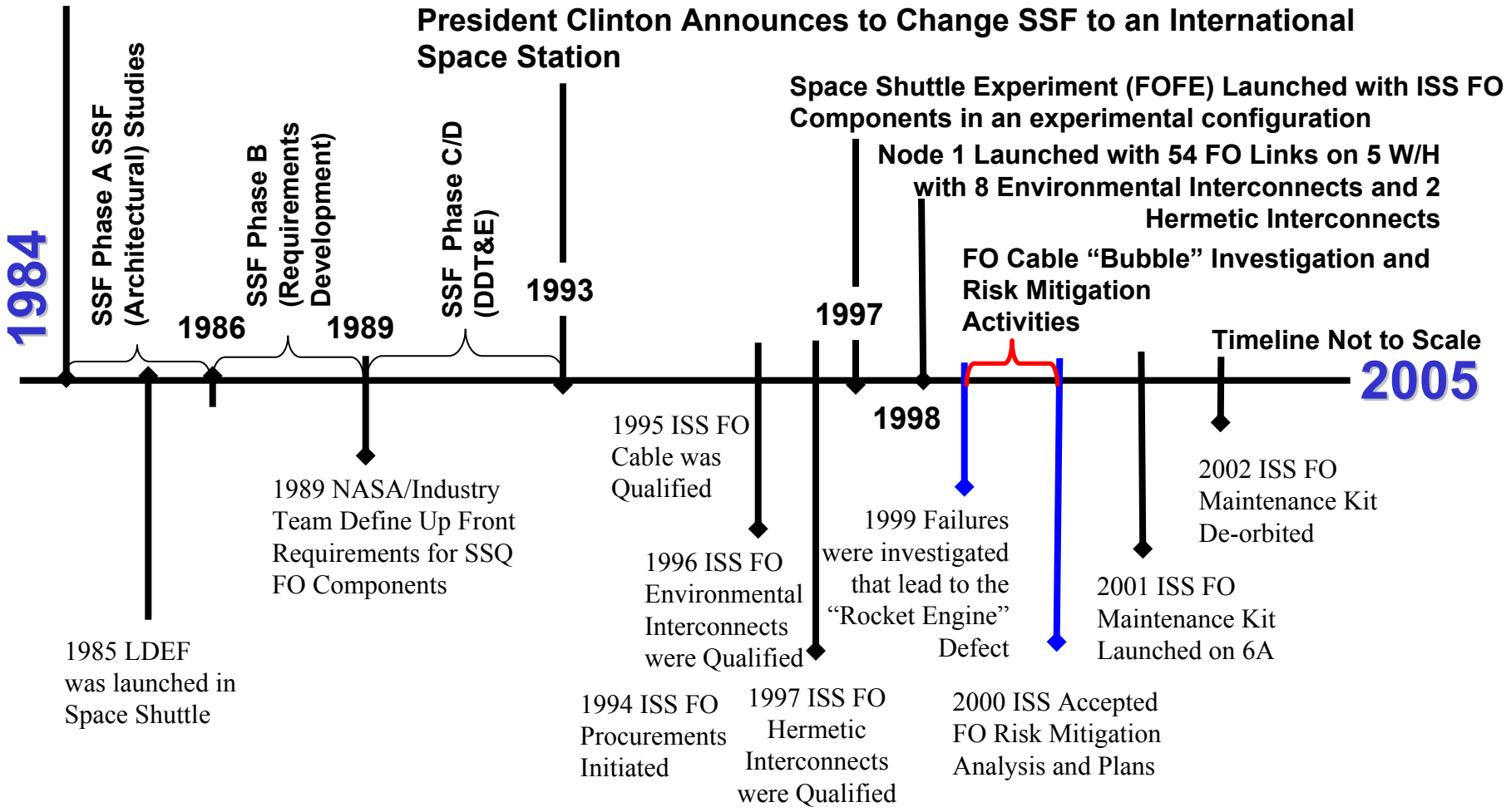
4/00	ATP for OTDR Development
5/00	OTDR Requirements Developed
7/00	ATP for FO Tool Kit Development
9/00	FO Tool Kit Requirements Developed
11/00	OTDR & FO Tool Kit Prototypes Completed
11/00	OTDR Outgas
10/00	OTDR Radiation Testing
12/00	FO Tool Kit Prototype Testing Initiated
12/00	PDGF Crew Walkdown with installation scenarios
12/00	OTDR Burn-in Testing
01-01	OTDR Vibration Testing
01/01	OTDR Thermal Cycling Testing
12/00 – 3/01	FO Cable Functional ATPs
3/01	Electrical Cable (28VDC) Functional ATP
1-3/01	Other COTS tools and miscellaneous Outgassed
3/16/01	Kit Sharp Edge Inspection
3/16/01	Kit Connector Fit Checks (IVA OTDR, Patch Cables, Reel, and all test adapters
3/20/01	Crew Walkdown and Bench Review
3/23/01	Stowage in MPLM Racks
3/26/01	Equipment Stowed in MPLM
3/26/01	Development Equipment used in Flight-like System Level Testing (still ongoing as of 6/9/01)
4/19/01	6A Launch
6/12/01	Operations Training Session
	FO Tool Kit Deorbited
	FO Tool Kit Placed in KSC Stores

FO Tool Kit Prototype Test Set

Crew Bench Review 3/20/01

ISS Journey to Utilize Fiber Optic Technology

President Regan Announces Permanent Manned Space Vision



As of September 2005, ISS has experienced 100% Success of Fiber Optic Components and there are well over a thousand links on orbit in operation