# ESCC Standards, evaluation and qualification of optical fiber connectors for space application

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*Abstract*— **Optical fiber connectors have been used for the past fifteen years in space application. Reviewing the heritage left from past and current mission, the status of ESCC standards for these components and assemblies will help future use of fiber in space applications.**

**In the frame of the ESA ECI program, Diamond has evaluated and is currently qualifying according to ESCC standards the AVIM and Mini-AVIM connectors. The configuration retained to qualify the connector sets is using a polarization maintaining fiber at 1550nm with a loose tube in PEEK as cable structure.**

**The evaluation has been used to step-stress specific characteristics of the optical fiber connectors with a particular aim at possible failure modes to establish a safety factor for the qualification. The evaluation results presented can be used on a case by case to evaluate special applications that would require to extend the specification.**

**The qualification components can be extended further and a structure for assemblies is proposed in order to simplify fiber optics implementation in space projects.**

*Index Terms — Fiber, optic, connector, ESCC, standards, evaluation, qualification, space. Diamond*

## I. INTRODUCTION

Fiber optic assemblies have been used for more than fifteen years in space applications and this paper presents the work accomplished so far by Diamond toward standardizing and qualifying components for these products under a ESA contract.

After a summary of the flight heritage which involved Diamond on some occasion, the status of ESCC specification standards is presented together with a comparison to IEC commercial standards.

Diamond's effort on the AVIM and Mini-AVIM evaluation following the existing basic specification and the results of this evaluation requires explanation especially on the failure modes.

The results of the evaluation were used in order to define the qualification test plan and propose a structure to fiber optic assemblies.

Finally, in the light of the present situation a small description on the actual procurement process status close this article.

## II. FLIGHT HERITAGE

Fiber optic connectors were used for different mission mostly for sensor applications (Laser altimeter, heat sensor,..), using large multimode or polarization maintaining fibers. With the increase in communication, more fiber has then been used to transport digital data, mainly using multimode fibers.

The higher densities in communication in satellites tends to increase fiber quantities leading to multi fiber ferrule based connectors or multi ferrules.

The AVIM connector, a special version of our original AVIO (for avionics), was designed with an hexagonal nut for Lockheed Martin [2] (Martin Marietta, hence the M on AVIM). The connector was qualified by Rifocs, our former distributor and partner in US and Lockheed Martin in the mid 90's. The AVIM version qualified at the time had a bi-component ferrule made of a tungsten carbide (WC) sleeve and a glued Nickel Silver insert. It has flown extensively on airplanes and on few other mission for NASA: GLAS[1,2,5] on ICESAT and on MLA[1]. The latter represents the Diamond connector closest to the sun and orbiting Mercury since the end of 2011.

*fig. 1 AVIM with WC ferule*

In the end of the 90's and early 2000's newer ferules using a ceramic ($ZrO_2$) sleeves and a Nickel-silver insert were brought to the market to be replaced in the mid 2000's by a titanium insert, which is to this day the standard technology used.

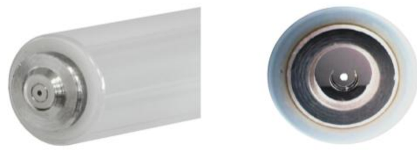

*fig. 2 Ceramic-Titanium ferrule*

These ferules and the AVIM connectors were used in several missions for connectorizing mostly MM large core fibers and PM fibers with cores down to 4um for operation at 660nm. SMOS [6] and Proba-2 were launched in nov. 2009. SMOS contains a large quantity of AVIM connectors while only a few are used on Proba-2.

Special multi-fiber ferrules have flown too on LRO in the LOLA[3, 5] instrument on a modified AVIM.

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The latest successful heritage are the AVIM connectors present on Curiosity, landed on Mars on 06-aug-2012 on the ChemCam [6] instrument.

To be noted, the presence on ELC [4], Atlid, Exomars, James Webb telescope and hopefully on many other mission.

The Mini-AVIM has been developed for space applications using the same anti-vibration system as the AVIM and using the same ferrule technology. It passed the evaluation and will be qualified and specified later this year. No heritage can be tied to this connector yet, but other evaluation have already been done[6].

*fig. 3 Mini-AVIM connection*

Updated information on public space application can be found on Diamond website at http://www.diamond-fo.com/en/markets_space_application.asp .

## III. ESCC CONNECTORS STANDARDS

The work presented here is part of a larger scheme by ESCC to write specifications allowing project manager to properly implement fiber optic technology for their project. For more information on these standards, please refer to the ESCC website at https://spacecomponents.org/ and for the specification details to https://escies.org/ .

The scope of the present work is the specification of optical fiber connector sets. If possible complete assemblies (patchcords and pigtails) built with fiber and cable should be tested too. As fiber and cable do not dispose of specification and qualification method as present in IEC standard, only the connector set should be qualified here.

The following figure corresponds to the IEC telecom standards for optical fibers and connectors.

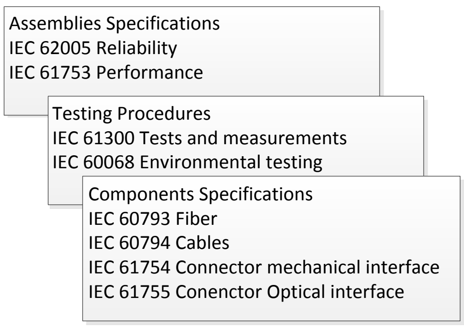


*fig. 4 IEC commercial standards overview*

### *A. ESCC Connectors standards*

The ESCC specification follow three levels consisting of Basic, Generic and Detail specifications that differs from IEC as shown below.

**Basic** specifications are applicable to components or groups of components and provide common processes and rules.

**Generic** specifications provide requirements and test methods applicable to components or groups of components.

**Detail** specifications provide a description of specific components or ranges of structurally similar components and give performance requirements, conditions of test, and approval, quality conformance and inspection requirements.

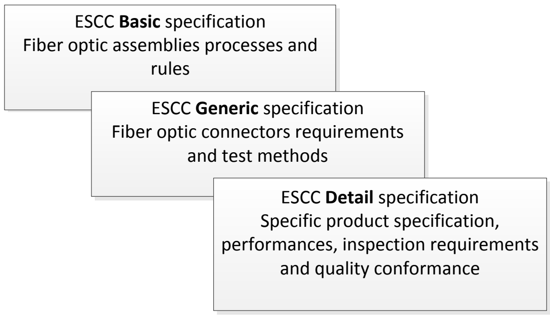


*fig. 5 ESCC Level 2, 3 and 4 documents*

Diamond interpretation in the range of optical connector set and optical fiber assemblies is as follow:

*1) Basic specification: 2263010:*

The Basic specification serves to define the evaluation test plan for **optic fiber assemblies** and the connector set. We evaluate that this corresponds to a reliability study in the IEC sense (62005). It is normally performed to evaluate failure modes and level and to fix the operational environment.

*2) Generic:TBD*

The Generic specification defines the qualification test plan and tests procedures. It corresponds to IEC Tests and measurements (61300) standards and the IEC performance (61753) standards for **optic fiber assemblies**.

*3) Detail: AVIM (TBD), Mini-AVIM (TBD)*

The Detail specifications defines the **connector sets** performance, geometry and include an annex with various performance obtainable depending on fiber/cable configuration. Diamond propose a fiber/cable structure to help standardize these assemblies.

The standard draft will be closed with this activity end 2012 and will be published early 2013 according to ESCC procedure.

## IV. EVALUATION RESULTS

### *A. Tested configuration*

As testing an optical fiber connector requires the use of a fiber and a cable, a study was performed to define which ones should be used.

A polarization maintaining (PM) fiber shows the optical requirement of a SM fiber and the sensitivity to stress similar to MM fibers and was picked for these tests. A good portion of the optical connectors for space are required with PM fibers. The Fujikura SM.15-P-8/125-UV/UV-400 was chosen due to the availability in large enough quantities.

A loose tube, OD=1mm in PEEK Victrex 450G was used as cable. Assemblies using this solution had been already qualified for space applications.

*B. Evaluation test plan*

Four groups of tests were performed: destructive, assembly, environmental and endurance tests. The complete evaluation plan is found in the annex. This evaluation test plan (ETP) was discussed with and approved by our technical monitor.

*C. Results*

The annex B. summarizes the results for both the AVIM and the Mini-AVIM. We will review some of the results of test found interesting hereafter, more details on the tests can be requested to the author, but represent 400 pages of reports for each connectors.

The cold part, from -80°C to -190°C was performed at SwissTS in Switzerland and liquid nitrogen was used to cool down progressively the connectors.

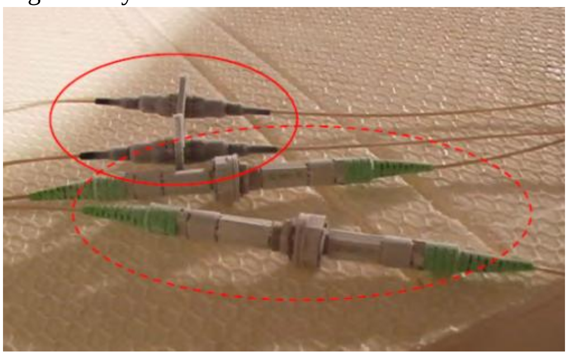

*fig. 6 Mini-AVIM and AVIM during cold temperature strep stress*

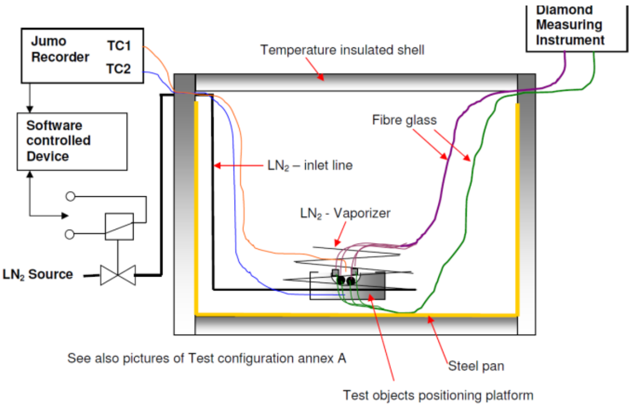


*fig. 7 Cold temperature step stress setup*

During the cycles, one Mini-AVIM cable broke at the end of the connector. The cause is a faulty assembly and this generated a change of the screening flow where we added a pull test at 5N, the limit for the connector, to root out manufacturing errors.

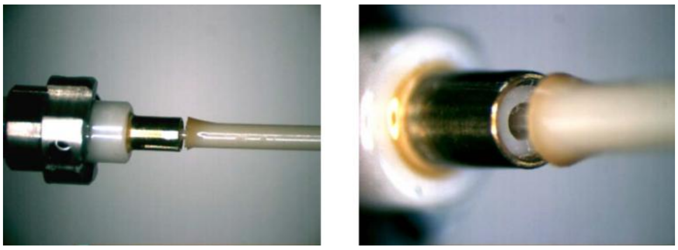

*fig. 8 Cable brake on the Mini-AVIM*

The vibration results were very interesting. An AVIM adapter fixing screw broke at 75grms causing the adapter to brake at 90grms. We replaced the adapter with an hexagonal flange version and repeated the tests without problems. For the Mini-AVIM, nothing happened and the results were excellent up to 90grms.

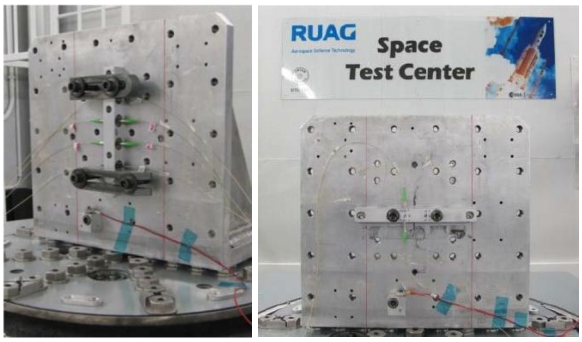


*fig. 9 Vibration table at Ruag Space*

In both cases, more pronounced on the AVIM, the end faces of the connectors showed evident signs of surface marks after vibration and shock. We decided to operate additional temperature cycles (ca. 100cycles) on the connectors to see if any type of problem could be induced later on.

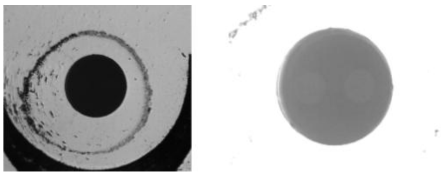

*fig. 10 Endface after vibration - functional*

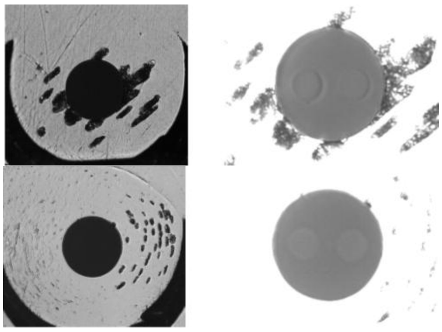

*fig. 11 Endfaces after shocks on AVIM - functional*

Slightly higher than usual IL was noted, but barely any variation on the RL and the ER. So long as the connectors are connected the endface markings do not cause problems.

At the end of these tests, an AVIM ferrule broke (the ceramic sleeve broke). The cause is unknown.

During the radiation tests performed at ESTEC, no radiation impact was observed on the connectors, but a clear impact was seen on the PM fiber. The following graph shows the absorption versus irradiation as measured during the exposure.

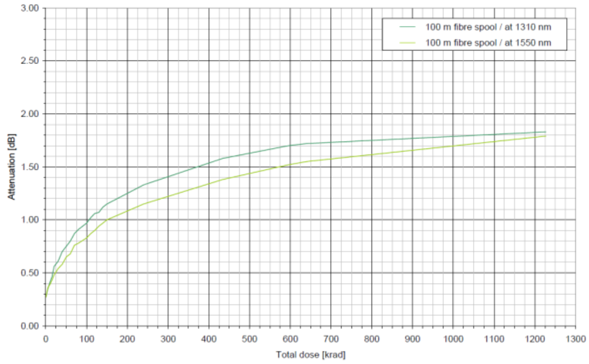


*fig. 12 Insertion loss on 100m fiber spool at 25°C for Fujikura SM.15-P-8/125-UV/UV-400. Dose rate of 8.14krad/h, 23.8°C, 34.8%r.h., 1019mbar*

During the mating-demating tests, thread problems were observed on the AVIM after 85 mating-demating. Material was removed from the thread and can cause a potential pollution of the optical interface. Endfaces were damaged after 200 cycles.

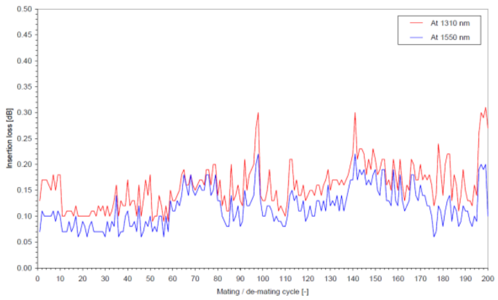


*fig. 13 Reproducibility of the AVIM*

The Mini-AVIM did not suffer even after 500 cycles, showing the positive effect of using titanium on titanium.

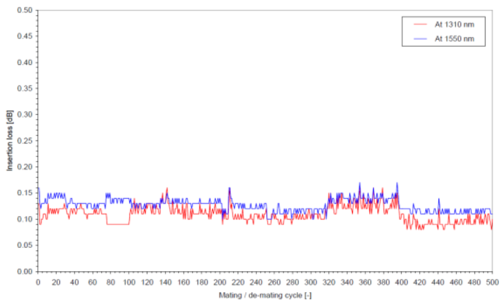


*fig. 14 Reproducibility of the Mini-AVIM*

## V. Qualification Specification

The qualification test procedure and levels was established after the analysis of the results of the ETP

The qualification is ongoing and partial results will be presented at ICSO2012 in Ajaccio, but no particular problem is foreseen.

### *A. Diamond proposal for fiber structure*

We would like to propose the following fiber structure:

Type a: Cladding < 130um (SM, PM, MM, PZ)

Type b: Cladding >130um (SM, PM, MM)

The reason for these two variations is that the functioning of a connector depends on the quality of the interface, which is guaranteed by the IEC standard for contact for fibers with 125um cladding (80um too). For larger fibers, contact can be OK, but probably different polishing parameters should be used. For large core, if the portion of the core is not in contact, what would happen in salt mist, dust or even vibration?

### *B. Diamond proposal for cable structure*

Three structures are proposed, there are non exhaustive:

Type i: secondary coated (tight or semi-tight buffer)

Type ii: loose tube seconday buffer (OD variable, one cylindrer)

Type iii: Structured cable (secondary buffer, aramid strands, third buffer)

For space, as little material as possible should be present around the fiber to minimize thermal problems.

The qualification will include the following:

1. AVIM connector
2. Mini-AVIM connector
3. PM fiber Fujikura SM.15-P-8/125-UV/UV-400 (and Type a)
4. PEEK cable loose tube (Type ii)
5. Assembled pigtail containing the above mentioned components
6. Assembled patchcords containing the above mentioned components.

## VI. Procurement Process

In order to dispose of qualified assemblies, the use of qualified connectors will be necessary, but not sufficient. The use of qualified fibers and cable is required too.

All other configurations must be qualified by the user. Diamond can offer production services and qualification services, but cannot guarantee qualified products. As Diamond connector sets can only be assembled by those company disposing of a Diamond updated production line, to this day only the headquarters of Diamond in Losone disposes of this capability.

New products based on the qualification results will be put on the market with easier purchasing process thanks to the work presented here.

## VII. Conclusion

We have presented here the work done so far on fiber optic connector specifications, evaluation and qualification. The results presented here on the AVIM and Mini-AVIM shows the maturity of these products for space applications and Diamond SA capacity to produce and, more important, assemble such products.

The qualification and specification about cable and fibers still remain to be finalized.

This has helped the community understanding better a product normally overlooked as part of connectivity, and helped Diamond understand the need of the community better.

## VIII. Acknowledgement

We would like to thanks the various external laboratory involved in this study, as well as our technical manager from ESTEC for the patience and support provided.

I would like to personally thank Mr. Patrick Rossini and his team. Mr. Rossini is the Head of our internationally accredited laboratory who has performed all the tests, locally or externally presented here. He produced the full reports with a precision and dedication to praise.

## IX. Reference

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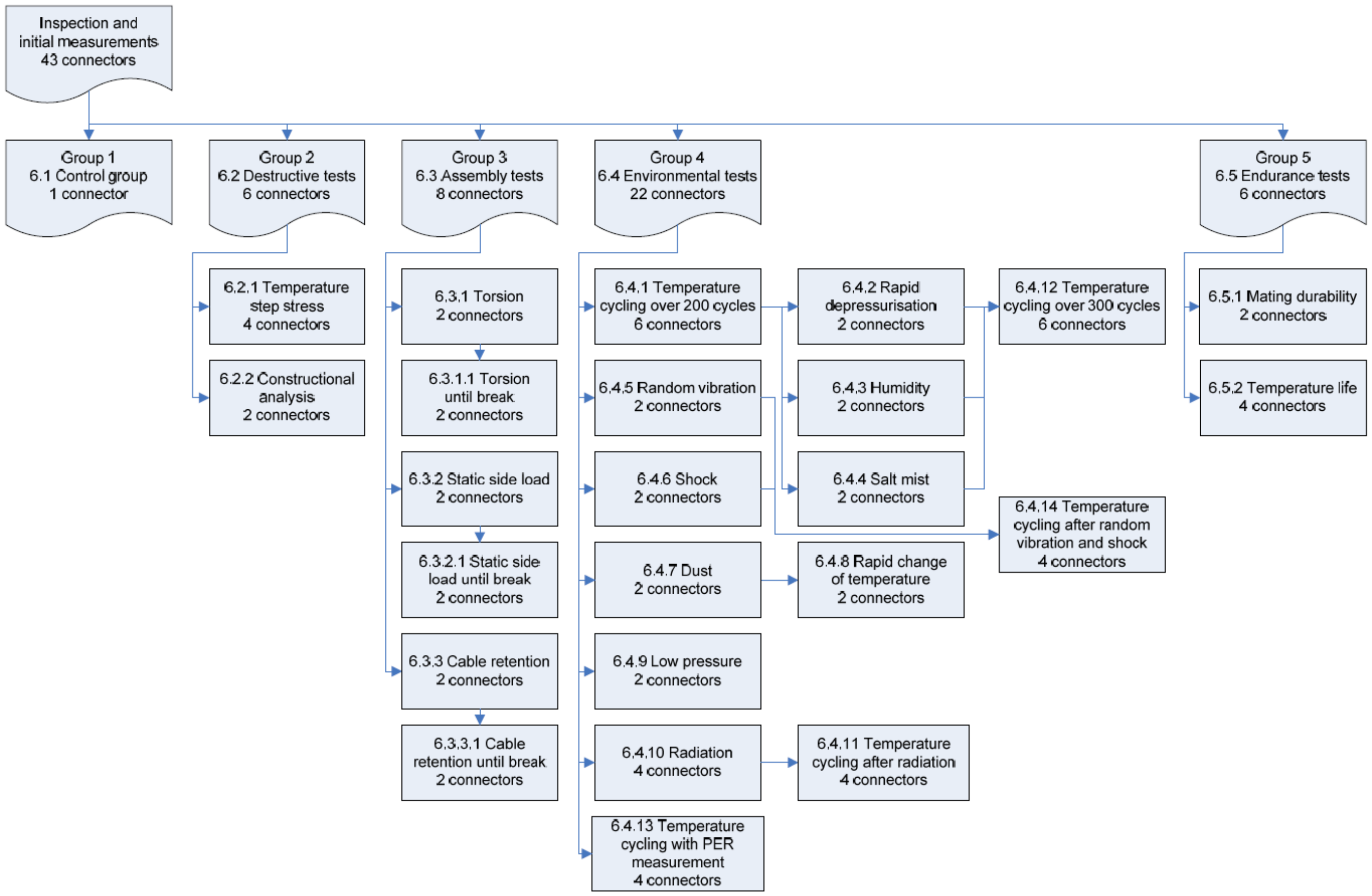
X. ANNEX

*A. Evaluation Test Plan*



| Test Nr. | Description | Qty | IEC standards | Test conditions | AVIM | Mini-AVIM |
|---|---|---|---|---|---|---|
| 6.1 | Control group | 1 | | | | |
| 6.2 | Destructive tests | | | | | |
| 6.2.1 | Temperature step stress | 4 | IEC 61300-2-18 | -190°C to +190°C, 1h per step | No failures at cold, .non reversible failure at 180°C.<br>Tmin=-55°C and Tmax=+125°C for environment and endurance tests | No failures at cold, non reversible failure at 120°C.<br>Tmin=-55°C and Tmax=+85°C for environment and endurance tests |
| 6.2.2 | Constructional Analysis | 2 | | n.a. | | |
| 6.3 | Assembly tests | | | | | |
| 6.3.1 | Torsion | 2 | IEC 61300-2-5 | a. to reversible<br>b. to break | No failures until reversible ferrule retraction (14N) due to spring. Torsion break point at 15N | No failures until reversible ferrule retraction (ca. 14N) due to spring. Torsion break point >50N, test interrupted at 50N |
| 6.3.2 | Static side load | 2 | IEC 61300-2-42 | a. to reversible<br>b. to break | Reversible failure up to 5N. Fiber break at 35N. | Reversible failure up to 4N. Fiber break at 15N. |
| 6.3.3 | Cable retention | 2 | IEC 61300-2-4 | a. to reversible<br>b. to break | Reversible failure up to 20N. Fiber break at 30N. | Reversible failure up to 20N. Fiber break at 60N. |
| 6.4 | Environmental tests | | | | | |
| 6.4.1 | Temperature cycling 200 | 6 | IEC 61300-2-22 | -55°C to +125°C/85°C, 1h dwell, 1°C/min<br>200 cycles | No problem | One connector broken (PEEK tube) due tomanufacturing error. |
| 6.4.2 | Rapid depressurisation | 2 | MIL-STD-810G, method 500.5, procedure III | 900mbar to 50mbar, <5s, 5 cycles, after 6.4.1 | No problem observed<br>Sent to 6.4.2, 6.4.3, 6.4.4 and then to 6.4.12 | No problem observed<br>Sent to 6.4.2, 6.4.3, 6.4.4 and then to 6.4.12 |
| 6.4.3 | Humidity | 2 | IEC 61300-2-46 | 95% r.h., +25°C to +55°C cycle, 6 cycles of 24h, total 144h after 6.4.1 | No problem observed<br>Sent to 6.4.2, 6.4.3, 6.4.4 and then to 6.4.12 | No problem observed<br>Sent to 6.4.2, 6.4.3, 6.4.4 and then to 6.4.12 |
| 6.4.4 | Salt mist | 2 | IEC 60068-2-11 | 5% salt, +35°C, ph 6.5..7.2, 85% r.h., 96h, after 6.4.1 | No problem observed, visible deposition of salt. Deposition caused damages at cleaning<br>Sent to 6.4.2, 6.4.3, 6.4.4 and then to 6.4.12 | No problem observed, visible deposition of salt. Deposition caused damages at cleaning<br>Sent to 6.4.2, 6.4.3, 6.4.4 and then to 6.4.12 |
| 6.4.5 | Random vibration | 2 | IEC 60068-2-64 | 25grms, 50grms, 75grms, 90grms<br>20Hz to 2000Hz<br>7.5min per axis | Adapter screw broke at 75g inducing ferrule damage.<br>Test reperformed with hexagonal adapter (no screws), performed up to 90grms (IL, RL and ER) with Il variation at 75g.<br>Visual damages of interface. Damages appearing at 50grms.<br>Sent 6.4.14 | Optically functioning up to 90grms (IL variation 0.1dBmax), but visual damages of interface. Damages appearing at 75grms.<br>Sent to 6.4.14 |
| 6.4.6 | Shock | 2 | IEC 60068-2-27 | 500g to 3000g on all axis | Transient loss around 2400g radially and 2000g axially.<br>Endface damages not preventing optical performances.<br>Additional temperature cycles after shock (6.4.14) | Transient loss higher than 3000g radially and 2000g axially.<br>Endface damages not preventing optical performances.<br>Additional temperature cycles after shock (6.4.14) |
| 6.4.7 | Dust | 2 | IEC 61300-2-27 | Red China clay, +30°C to +65°C, < 30%r.h., 8.9m/s, 6g/m3, 1h | No problem observed<br>Difficulty cleaning, induced scratches on fiber | No problem observed<br>Difficulty cleaning, induced scratches on fiber |
| 6.4.8 | Rapid change of temperature | 2 | IEC 61300-2-47 | -55°C to +125°C/85°C, 10 cycles<br>30min dwell, transfer < 1min | No problem observed | No problem observed |
| 6.4.9 | Low pressure | 2 | IEC 60068-2-13 | 4*10-8 Torr, ambient, 8h | No problem observed | No problem observed |
| 6.4.10 | Radiation | 4 | ESCC 22900 | $^{60}$Co, 1180 krad total, 8.14 krad/h, ambient | No problem observed on connector.<br>Fiber with logarithmic absorbion curve | No problem observed on connector.<br>Fiber with logarithmic absorbion curve |
| 6.4.11 | temperature cycles after radiation | 4 | IEC 61300-2-22 | -55°C to +125°C/85§C, 1h dwell, 1°C/min 10 cycles | No problem observed | No problem observed |
| 6.4.12 | temperature cycles after 6.4.1, 6.4.2, 6.4.3, 6.4.4, 300h | 4 | IEC 61300-2-22 | -55°C to +125°C/85°C, 1h dwell, 1°C/min<br>300 cycles after 6.4.2, 6.4.3, 6.4.4 | Salt mist connectors showing above normal but stable IL. One ferrule broke after 300cycles at un-mounting but optical parameters were good | Salt mist connectors showing above normal but stable IL. One connector variation >0.4dB |
| 6.4.13 | temperature cycles with ER measurements | 4 | IEC 61300-2-22 | -55°C to +125°C/85°C, 1h dwell, 1°C/min, 3 cycles | No problem observed | No problem observed |
| 6.4.14 | temperature cycles after shock, vibration | 4 | IEC 61300-2-22 | -55°C to +125°C/85°C, 1h dwell, 1°C/min, 96 cycles (AVIM), 100cycles (Mini-AVIM) | No problem observed. Few IL variation at 0.4dB | No problem observed. Few IL variation at 0.4dB |
| 6.5 | Endurance tests | | | | | |
| 6.5.1 | Mating durability | 2 | IEC 61300-2-2 | 500 mating - demating | Metal debris not impeding function observed after 85 cycles, endface damage at 200 cycles | No problem seen. |
| 6.5.2 | Temperature life | 4 | IEC 61300-2-18 | 5000h at 125°C/85°C | No optical problem on IL, RL or ER. One connector with fiber withdrawal below limit.<br>Degradation of the antiflexion boot | No optical problem on IL, RL or ER. two connectors with fiber withdrawal below limit. |