Optical fiber interconnect: Standards, Procurement, lesson learned and future applications

Frédéric Taugwalder
Diamond SA, via dei Patrizi 5, 6616 Losone, Switzerland

ABSTRACT

The ESCC has published new optical fiber connectors standards destined to simplify procurement of such components. A summary presentation is given, but more importantly, how to use them, the lesson learned from Diamond's perspective is presented. The latter cover the fiber lot management, the radiation and a few other parameters necessary for projects.

Three main application categories are presented: A) Generic-Sensing, B) Satellite external communication, C) Satellite internal communication. Their products range and covered solution is presented, with potential new development proposed

Keywords: Optic, Fiber, Connector, AVIM, Space, Radiation, ESCC, 3420.

1. INTRODUCTION

Following ESCC publication of standards for optical fiber assemblies, Diamond is sharing its experience with other user with the scope to help mission engineer plan their mission. Properly understanding the benefit and limitation of standards has been difficult, but with the increasing number of fiber optic application, we hope to avoid problems found in the past, putting pressure on suppliers as well as on end-users.

ESCC standards for Test and product description give stakeholder access to a common information platform for space applications and products.

Lesson learned during the first 12 month of use for these standards should help the stakeholder to better manage projects including fiber optic interconnects.

Sorting the applications into three types, Sensing, Inter-satellite and intra-satellite communication application, allow to present solutions to common applications. Though limited, this sorting might change to allow new application family to be described separately as presenting specific technology/product requirements.

2. ESCC STANDARDS

The following presented ESCC standards for fiber optic are available at www.escies.org.

Keep in mind that the object to be specified is an optical fiber assembly including fiber, cable, connectors and mating adapter.

We use the more broad terminology of optical fiber interconnect to talk about all the solutions dedicated to connectorize optical fiber(s) by contact or in air, single or multi-channel.

2.1 ESCC 2263420[1]

The Basic Specification purpose is to define the tests necessary to find the failure modes in various environments (temperature, vibration, vacuum, etc.) and to derive the qualification specification.

Any new configuration variant changing enough the product might have to be submitted to all or a portion of the tests described in this standards.

All new product should be submitted to the entire program, with the same scope in mind: finding failure modes.

2.2 ESCC 3420[2]

The Generic Specification purpose is to define the tests and procedure to qualify an optical fiber assembly and all the tests and procedure necessary to do so.

This is a generic document to be applied to all connectors. Additional tests or partial tests might be necessary and are normally described in Detail Specification such as the following one.

2.3 ESCC 3420/001[3]

This Detail Specification, dedicated to Diamond Mini AVIM™ defines the structure, performance and deviation from the Generic Specification. Not all variant are qualified.

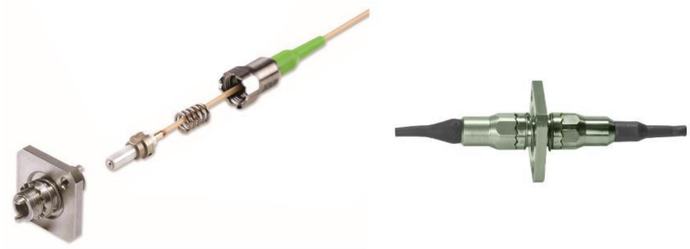

Figure 1 Mini AVIM™

2.4 Good practices

Detail specification such as 3420/001 summarize the configuration available and the performance given, but does not contain Qualification status. A Qualification Part List (QPL) certificate usually describes which variants or configuration are qualified.

Such specification and QPL do not guarantee that a qualified product is adequate for a mission. Mission manager must verify the latter and product supplier have not the understanding of the application in order to take this responsibility.

Mission requirement requiring tests beyond the ones used in qualification should be define and requested from the suppliers. For example, if a higher requirement in shock than the one used for qualification is required, a supplier knowing the failure mode in shock might have data to respond or will have to create new data by testing. In case of test failure, further development will be necessary until test are passed. The time and cost for such should not be underestimated.

Previous tests will help minimize mission qualification [4] by using already existing data

2.5 General procurement flow

The ESCC 3420 general procurement flow is clear, if a configuration (connector+fiber+cable) is not already qualified (covered in the QPL or disposing of similar test results); a specific qualification is required for each lot.

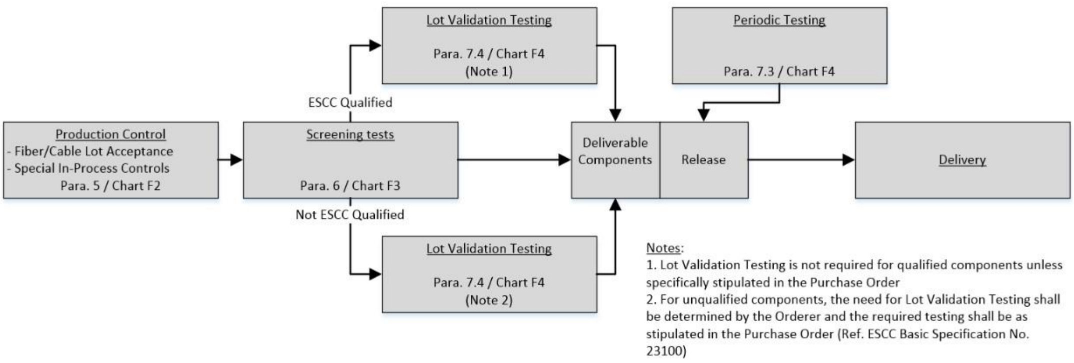

Figure 2 ESCC 3420, issue 1, p. 30, Chart F1, see full document for complete reference

3. LESSON LEARNED

3.1 Fiber management

As fiber lots require radiation and outgassing data, each mission should plan to manage fiber for the whole mission. This means defining the right fiber with all their suppliers, and then procuring one lot that will be radiation and outgassing characterized. Alternatively, these specifications can be pushed down to fiber manufacturer.

Beware that the fiber quantity can increase dramatically depending on the specification requirement, as extra lot must be used to qualify those new specifications.

The fiber quantity is always underestimated early in the project and a detailed evaluation of the quantities should be performed involving all the suppliers.

Simply relying on fiber/cable manufacturer is not enough according to Diamond experience, as many parameters are not specified.

As the cost of the fiber compare to such a project is normally low, especially compared to the qualification costs for example, a lot large enough should be procured.

3.2 Radiation / Outgassing tests

Radiation and outgassing characterization of the fiber [5][6][7]must be performed or their values required from the manufacturers, before even specification can be finally written.

The radiation tests are normally done by connectorizing long Patchcord and then submitting the bare fiber only to the radiation while measuring the relevant optical parameters. Enough fiber quantity must be used (100m) if possible.

The temperature, light intensity have an impact on those behavior, and specialist [8]for these types of measurement can be used.

Submitting early on the fiber to those tests is a good practice too, if a problem is discovered at this time with the fiber, project(s) can still change it.

3.3 Optical performance

Digital data transmission is a well-documented application. For all others application defining the appropriate optical parameter influencing the application and susceptible to be disturbed by a fiber optic assembly is essential to the fiber optic interconnect requirement definition. The standards have probably not anticipated all the use of the fiber optic and might miss a key optical parameter in its specification.

The choice of product, their adequacy to the application will depend on these requirements and over-specifying and under-specifying have consequences in the time plan and the costs, making both increasing sometimes dramatically.

3.4 Visual inspection

Visual inspection CANNOT be substituted for optical parameters (IL, RL, PER, etc.) measurements and should not be used as pass/fail criteria.

Diamond 40 years' experience, as well as data from the evaluation and qualification phase of all the space connectors have clearly demonstrated that there are very low or no correlation between the visual inspection and the optical performance and failure of a connector.

Visual inspection is used to verify the assembly for cosmetic reason at the manufacturer plants. The actual ESCC 3420 standards are based on a restricted version of IEC 61300-3-35. Except for brand new connectors, this version is too restrictive.

The state of the art concerning critical connector verification contains all the defined performances (IL, RL, PER, endface geometry). Connector history documentation should contain pictures of the endface, but the visual inspection should normally not be used as pass/fail. Automatic analysis system are known to be un-reliable and video assisted or direct human inspection to document the history of a connector is advised.

3.5 Reliability

Predicting the lifetime or the EOL performance is often requested. To do so, a reliability model should be available and so far, only models based on semiconductor physics have been used. Those have be clearly based on physics not easily applicable in the case of an optical fiber connector in space.

The development of such a reliable model is the serious pre-requisite to lifetime and de-rating calculation, not only for space application, but also for all commercial ones. The market return of millions if not billions of installed telecom connectors cannot be easily extrapolated for space application and the 100's connectors in space do not constitute a large enough statistical group of similar connectors.

Thousands of hours of various test performed for IEC or Telcordia qualification, but they are not related to a clear model yet.

4. SPACE APPLICATION

Over the last 20 years that Diamond was involved in Space activities, we have seen a lot of various application and the following is our proposition on how to structure them. The scope for this structure is to already simplify the amount of products and define which products is required for present/future application.

4.1 Generic Sensing

The sensing application are numerous, probably driven by Lidar or Laser Altimeter[9], but numerous other application have been used, using optical fiber from low wavelength, small core single mode polarization maintaining to large core multimode.

It is almost impossible to standardize those applications. The important optical performances defining the qualification pass/fail vary with each application. Standard digital communication are quite robust and tolerate a wide variation of performances, while sensing application can be very sensitive to wavelength, intensity, phase, polarization or other light properties.

Figure 3 Generic Sensing applications

Typical products are single channel connectors with any kind of other solution including ferrule, collimator, multi-channel, high power, etc.

Multi-channel will appear here, but as sensors[10] are often based on sensitive analog signal, the requirement of the optical interconnect might require specific solutions.

Other expanding application are FBG based sensing (temperature, strain)[11] which might benefit from using PICS (Photonics ICs)[12] who can perform a part of the processing in optics, further minimizing weight, power, insensibility to EM radiation.

Opto-pyro application [13], the art of explosive disconnection by means of a high power laser, could represent a future interesting optical fiber interconnect challenge due to high power, performance required and reliability. Position in the Generic-Sensing group, it could become a new application family in itself.

Figure 4 Diamond AVIM Family harsh environment resistant connectors

4.2 Inter-satellite communication

With optical signal, a line of sight is necessary to bring the data on the ground. As this is not always possible from all satellite position, inter-satellites communications will be required and could be extended to planes, unmanned vehicle or even balloon. Constellation of thousands of satellites are discussed, each would require a communication terminals, which are already commercially available or in development.

Optical modulators [14] are a necessary component and often use polarization-maintaining fiber requiring adequate connectivity. Vacuum, high power application have already been used [15] and some heritage exist. Radiation test on EDFA, one important component for this has been already presented [16]

Any connectors would be stressed by the power used for those long distance communication beams and will require new solution developments.

Figure 5 Multi-satellite communication constellation

From the market, multi-channel connectors, in typically 5-10 cm3 connectors for high power or any type of interconnects seems a requested products and should be further investigated.

4.3 Intra-satellite communication

Telecom satellite are using up and downlink using radio waves and use electric cable internally (several tons).

The challenge to change these payloads in fiber optic [17][18][19][20], improving dramatically weight, power dissipation and power consumption can change dramatically the face of communication via satellite. A typical telecom satellite would have a thousand connection to be replaced by optical fibers. Here the difficulties are not the optical performance, but more the volume per channel.

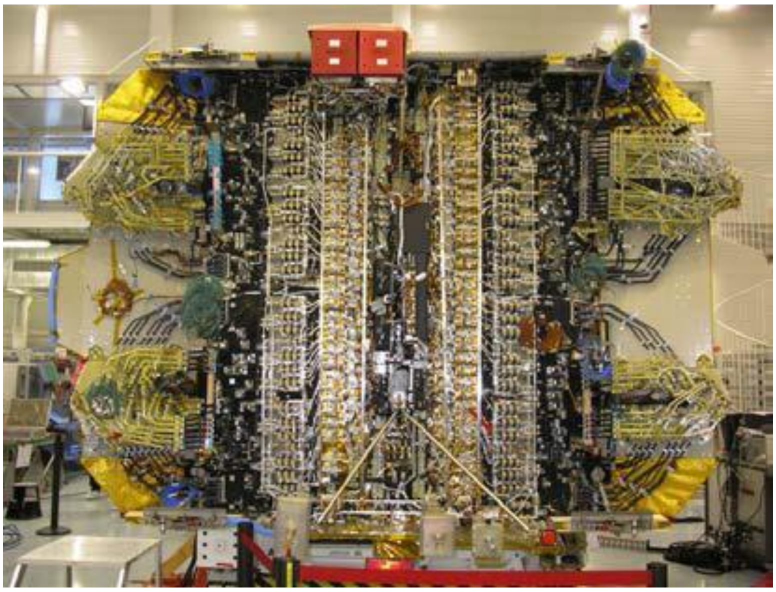

Figure 6 Typical Payload Panel Equipment Layout (Eurostar E3000 Platform) using conventional RF equipment. [19]. Imagine 1000 optical fiber and connectors binding modules on that scale.

The products here will be based on multi MM MT base ferrules optical interconnect, for transceiver in particular [21][22]. Connectors based on the MT standard have already been used in space applications [23]

Products exist already for these kind of applications on the market, and standards will be adapted to those solutions.

A hybrid solution for electrical connection through optical links has been investigated [24] and products exists.

5. ROADMAP

As described above the following two product families are missing from the standards for space applications:

- Miniature multi-channel connector for high power PM applications. A conceptual idea of volume shown below (Figure 7, left), next to a single channel AVIM™ connector.
- Multiple MM MT based optical interconnects. A conceptual delivered product based on Diamond MFS connector shown below (Figure 7, right)

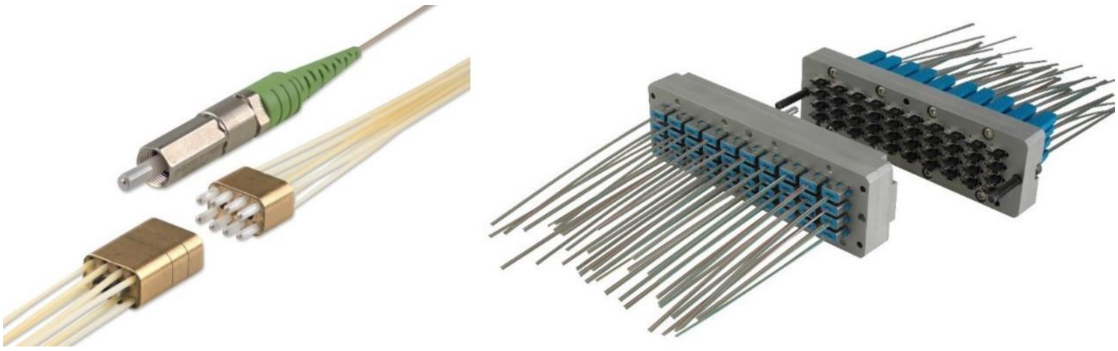

Figure 7 Example of product to figure on a roadmap: Left a multi-channel single ferrule and right, Diamond realization for a CERN deployed 640 fibers connector

6. CONCLUSION

The ESCC optical standards have been presented and its appropriate use and limitation proposed. Changes in the standards and future QPL releases should be monitored regularly to maintain updated information on the fiber optic connectors.

The important lesson learned, especially with fiber management are presented with the hope to improve speed for managing mission needs. Defining the needs as early as possible help to maintain schedule.

The application structure presented is meant to be used as an indication for users what type of solution to look for and what has already been developed. It is not exhaustive but present past realizations.

Diamond will look toward new product developments depending on market demands but dispose already of all the building blocks to expand its catalog of solutions for all the space applications.

REFERENCES

[1] Evaluation Test Programme for Optical Fiber Cable Assemblies, issue 2, ESCC, February 2018

[2] Optical Fibre Cable Assemblies with signle Fiber Ferrules, Generics, issue 1, ESCC, June 2017

[3] Optical Fibre Cable Assemblies with single fibre Ferrues based on type Mini-AVIM, issue 1, ESCC, June 2017

[4] Optical fiber technology for Space: Challenges of Development and qualification, OHB, Hans Thiele, Michael Goepel, ICSO conference, 2014

[5] Performance of optical fibers in space radiation environment, Nufern, M. Alam et al.., ICSO conference, 2006

[6] NASA Electronic Parts and Packaging Radiation Effects Summary Database on Commercially Available Optical Fiber September 18, 2009, NASA GSFC, Melanie N. Ott et al.., 2009

[7] Radiation tolerant passive and active optical fiber products for use in space environments, Fibercore, Mark Hill, Judith Hankey, Rebecca Gray, ICSO conference, 2014

[8] Radiation tests on optical fibers: good and bad practice, Fraunhofer INT, J. Kuhnhenn, ICSO conference, 2014

[9] The fiber Optic system for the Avanced Topographic Laser Altimeter System (ATLAS) instrument, NASA GSFC, Melanie N. Ott et al.., SPIE conference, 2016

[10] Fiber-optical Sensing on-Board Communication Satellites, OHB, Philipp Putzer, ICSO conference, 2014

[11] Fiber Optic Sensing subsystem for temperature monitoring in space In-Flight applications, FiberSensening, Silvia Abad et al.., ICSO conference, 2014

[12] Space Gator: a giant leap in fiber optic sensing, Technobis fibre technologies, Rolf Evenblij, ICSO conference, 2014

[13] Optical Pyrotechnology for Launchers and Satellites, Kongsberg, E. Livermore al.., ICSO conference, 2014

[14] Optimization and evaluation in space conditions of multi-GHz optical modulators, iXblue-Photline, Henri Porte et al., ICSO conference, 2014

[15] Qualification testing of fiber-based laser transmitters and on-orbit validation of a commercial laser system, JPL, Malcolm W. Wright, Marcus W. Wilkerson, Renyong R. Tang(Nuphoton Technologies), ICSO conference, 2014

[16] Radiation-hard Mid-power Booster Optical Fiber Amplifiers for High-speed Digital and Analogue Satellite laser communication links, Gooch & Housego, L. Stampoulidis et al., ICSO conference, 2014

[17] Reconfigurable Microwave Photonic Repeater for Broadband Telecom Missions: Concepts and Technologies, Thalès Alenia Space, M. Aveline et al.., ICSO conference, 2014

[18] High-Throughput optical inter-board interconnects for next generation on-board digital transparent processors, Thalès Alenia Space, N. Venet et al.., ICSO conference, 2014

[19] Towards Telecommunication Payloads with photonic technologies, Thalès Alenia Space, S. Vono et al.., ICSO conference, 2014

[20] Application of Photonics in next generation telecommunication satellites payloads, Airbus D&S, J. Anzalchi et al.., ICSO conference, 2014

[21] Fiber-Optic Transceivers for high-speed Digital Interconnects in Satellites, VTT, Mikko Karppinen et al.., ICSO conference, 2014

[22] Chip-Scale Package fiber optic transceiver integration for Harsh Environments, Ultracomm Inc., Chuck Tabbert, ICSO conference, 2014
[23] HERMOD: Optical payload technology demonstrator flying on Proba-V, ESA, S. Hernandez et al.., ICSO conference, 2014
[24] Active Optical cable for intra-satellite communications, DAS Photonics, J. Blasco et al.., ICSO conference, 2014