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ABSTRACT

Stricter requirements for data transmission, such as harness weight, data bandwidth and attenuation, have caused a rising demand for fiber optical (FO) solutions in the space market. The market is in need of solutions that are able to accommodate a high number of fibers, be highly customizable and have a low assembly, integration and test (AIT) time.

In this context we present the development of the Fiber Optical Flexible Routing Assembly (FOFRA) under the ARTES 5.2 programme. The FOFRA is a thin and flexible optical circuit board that offers a protected layout environment for fibers in a systematic high-density pattern. Today, the FOFRAs are produced for jet fighters and other applications.

Routing a larger number of fibers is a time-consuming and meticulous task which requires an optimized systematic design with a high routing precision. A fiber optical routing machine has been developed together with a routing software for this application. It has been demonstrated that these tools can produce a large variety of FOFRAs regarding size, shape, material and fiber I/O interface. The FOFRAs can be manufactured using materials with good space experience. The MT-ferrule has been selected as the preferred interface option. Several variations of FOFRAs will be presented.

Keywords: Fiber Optics, Circuit, Board, Flexible, FOFRA, OCB, Fiber Bragg Grating, FBG, PM-FBG

1. INTRODUCTION

Fiber optics have been in the market for decades, but the application of the technology to the space segment has been limited. However, satellites as SMOS [1] and Proba-V [2] used FO successfully. For mass use all general components needed for FO systems are not fully qualified yet. The benefits of optical communication are in line with the desired requirements of hardware in space such as low mass, electromagnetic interference immunity, high data transfer speed and absence of galvanic issues. Fiber optics and especially Mechanical Transfer (MT) ferrule technology (12-72 fibers in less than 20 mm^2 interface) reveals a great opportunity for saving volume, power, weight/mass, having an increased data transfer speed compared to conventional copper technology. It is also important to recognize the value of reducing AIT time to a minimum.

This paper introduces the FOFRA and the development of the technology under the European Space Agency (ESA) ARTES 5.2 programme (4000117900/16/NL/US). Product requirements and manufacturing challenges will be identified and addressed. Several markets have been identified to benefit from the use of FOFRAs. The work presented in this paper will concentrate on the space market.

In telecom satellites, to accommodate higher bandwidths per channel and being able to compete in the market, fiber optics will effectively be replacing copper interconnections in the near future for more channels and better bandwidth. There is a need for FOFRAs for the Digital Transparent Processor (DTP) technology to accommodate the routing complexity and high density of channels. Another possible application is the market of fiber optic sensing systems, where fibers with sensors, such as Fiber Bragg Gratings (FBGs), can be placed on a larger FOFRA to be mounted directly on spacecrafts to significantly lower the AIT time.

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2. FOFRA DESCRIPTION

A FOFRA is an Optical Circuit Board (OCB) which can accommodate a high amount of fibers and FO connectors for any type of system interface. The shape, size and thickness will vary greatly depending on the application, limited by the routing area of the machinery and the complexity of the product. By default, the FOFRA contains only passive components, with the possibility of manual implementation of active components if this is desired. Today, only primary coated fibers of ≤250µm nominal diameter is routed by machine. The contents on the OCB are encapsulated with Kapton polyamide layers and/or a selection of adhesives to fix the position of the fibers and other components to the board.

The selection of manufacturing materials has been determined by parameters such as temperature range, outgassing and space experience. Furthermore, the adhesives and ribbon coating materials must have the right tackiness and durability, but also the right viscosity and cure time for the liquids to able spraying and proper curing procedures. Loss/reliability property in relation to fiber for product temperature range is also important for this selection. All components not part of ferrule termination, are inert. There is an interest in using Commercial Off-The-Shelf (COTS) fibers for telecom satellite DTP applications.

In the last two decades, there has been an increased interest of MT and MTP/MPO for harsh environment applications [3-4], where both ESA and NASA have successfully demonstrated the technology in space environment. Based on current requests, it is expected that the MT ferrules will continue as the preferred connector for most FOFRA space applications.

2.1. Challenges

Working with primary coated fibers, it is important to understand the effects of micro- and macrobending induced attenuation. Macrobends refers to the minimum bending radius of the fiber. With the advent of bend-insensitive optical fibers (BIF), the higher threshold for macrobending induced losses allows for routing with low bend radii. However, low radii directly impair the lifetime of the fiber [5] and should be kept well above the recommended minimum bending radius. Fibers for the FOFRA are routed with a minimum radius of 15 mm. Permanent bends are much more critical than temporary bends but both types should be kept as large as possible compared to routing requirements (density, complexity of layout).

The main cause of macrobends in the FOFRA is fiber crosses, where fibers are routed on top of others. Macrobends as a cause of fiber crosses can be alleviated in two ways, depending on the complexity of the design and fiber density for the FOFRA. When designing the routing pattern, the fibers are grouped together whenever possible so that the number of crossing points are minimized. When these crossings are identified, the fiber layout sequence will be determined and the crossing points are then spread out to prevent fiber braiding. The other way is by material selection, where the right adhesives and thickness reduce the fiber cross height and provide support against external pressure.

Microbends are microscopic bends or deviations in the core-cladding interface that can cause signal attenuation and decrease the lifetime of the fiber. The FOFRA is manufactured in a cleanroom where the routing surface is as clean as possible. Any particles that may be present on the surface will give little to no microbending effect. Thus, the main cause of microbends can be attributed to stresses on the fiber. This can be minimized by routing the fiber well within the macrobending specification on a surface with an adhesive that allows the fiber to relax excess forces. In addition to added fiber protection against moisture and external forces, laminating the flex and encapsulating the fiber in a soft adhesive help minimize stresses by absorbing changes in temperature where deviations in the thermal expansion coefficients of the flex components cause negatively affects the lifetime of the product.

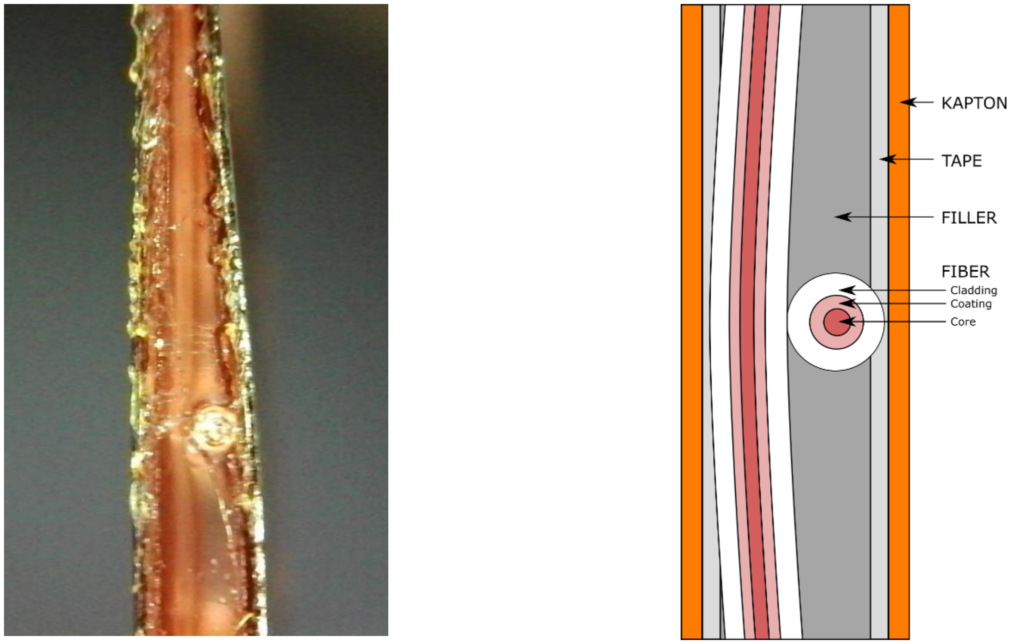

Figure 1: Cross section picture (left) and sketch (right) of a FOFRA laminated with an adhesive. The outline of the crossing fiber can be seen in the background

Figure 1 shows the cross section of a FOFRA, demonstrating the effectiveness of fiber protection. The figure to the right is a representation of an ideal lamination, where the flex has a uniform thickness to distribute any external forces applied on the flex over a larger area.

Obtaining the best results of fiber ribbonization requires an adhesive that is within a certain degree of viscosity and good wettability to fill the voids between the fibers. In general, the selection parameters include temperature range, outgassing and viscosity. It is worth noting that the hardness of the cured material is of less importance as the thickness is in the order of tens of micrometers.

3. PRODUCTION SETUP

Fiber routing is the most critical process in FOFRA manufacturing, where the fiber needs to be routed with maximum accuracy and minimum stress. FOFRAs with a high fiber density requires an automatic routing process to make correct routings with high repeatability. For FOFRAs with a low fiber density, it is in certain cases possible to route the fibers manually for good results.

In 2013, T&G Elektro initiated the task of developing a custom designed fiber optical routing machine by an external Norwegian manufacturer. The machine was completed and installed in 2014, but is still going through design changes and improvements with the latest addition being an improved new cutting method in Q4 2018. Manufacturing flexes requires a large sticky surface for the fiber to adhere. For this reason, the machine is installed in a clean room facility, where dust particles and aerosols are kept to a minimum.

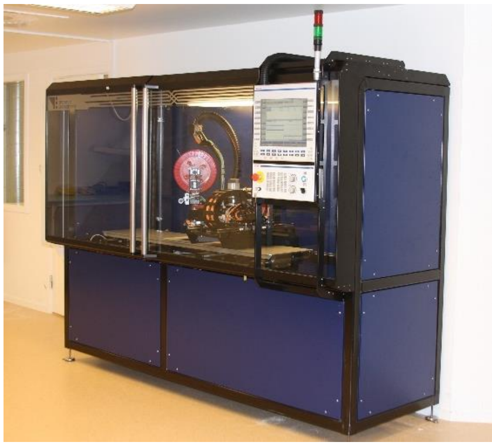

Figure 2: Fiber optical routing machine in clean room conditions

The FOFRA designs are created using Computer-Aided Design (CAD) software with inputs on FOFRA shape and fiber I/O configuration. Drawing the designs and making optimum design choices are tedious and difficult tasks when the designer is left with the functions provided by the CAD programs. To address this issue, a fiber optical routing software was developed and completed in 2017, adding additional tools to help with the design and saving time. The CAD drawing is exported to a third-party software for post-processing, generating G-code that runs on the routing machine. Figure 3 shows an example of a routing design with a prototype routing.

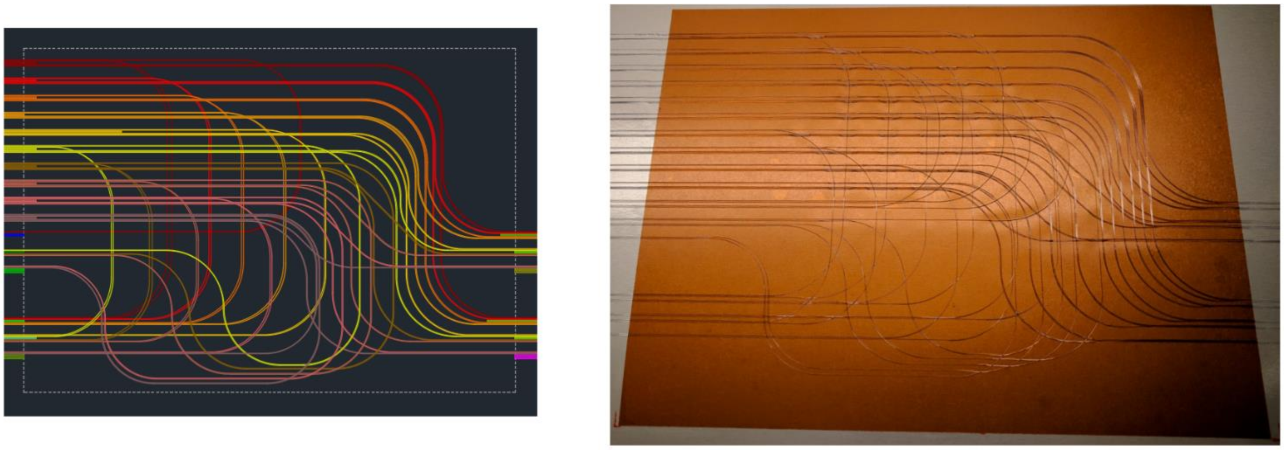

Figure 3: FOFRA CAD drawing created using the functions from the fiber routing software (left). Each connector has a separate colour to simplify the design process. A prototype routing of the design including some alterations where some fibers by choice are omitted and some are moved to different positions on the flex (right).

4. RESULTS

4.1. Telecom satellite DTP

Two FOFRAs have been manufactured and mounted in a demonstrator test rack, shown in Figure 4. The demonstrator was manufactured by Thales Alenia Space (TAS), Toulouse, to show the technology in an early stage of the project. T&G Elektro and TAS have since been working together with new designs that are to be manufactured and tested in Q4 2018.

Figure 4: DTP FOFRAs in a demonstrator test rack

FOFRAs for telecom satellite DTPs are characterized as complex with a high fiber density. The MT ferrule is identified as the main ferrule for these FOFRAs. Figure 5 below shows an insertion loss distribution of 478 standard version Multi-Mode (MM) MT to MT ferrules, with MM OM2 fibers, from 20 FOFRAs manufactured for a customer in the aerospace industry with a requirement of < 1 dB loss. The data includes losses from 1-2 m lengths of fibers, with an average of approximately 20 cm being routed on the flex. It is expected that using the MT Elite ferrule from US Conec will improve these results.

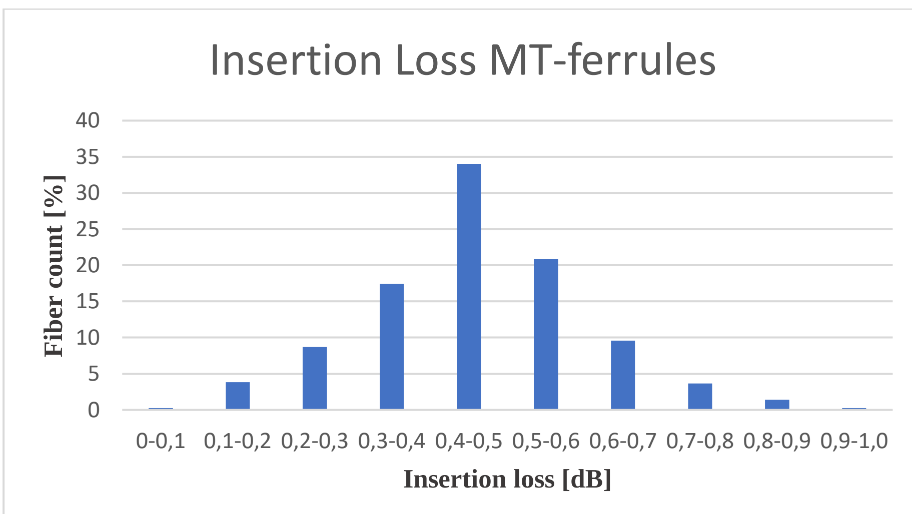

Figure 5: Insertion loss measurements of 478 standard non-elite type MM MT-ferrules from 20 FOFRAs. The test has a total of 1128 measurements.

4.2. Fiber optical sensor systems

A FOFRA with two Polarization-Maintaining FBGs (PM-FBGs) has been manufactured and tested with the purpose of demonstrating the accuracy temperature measurements when mounted in an OCB, shown in Figure 6 [6]. The PM-FBG sensors were draw tower gratings manufactured by FBGS using Oromocer coating. The FAZT I4_Bi tuneable laser interrogator platform was used to acquire data.

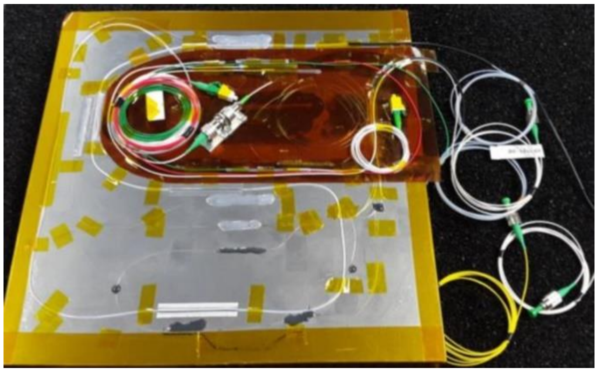

Figure 6: Panel with FOFRA and optical sensors installed

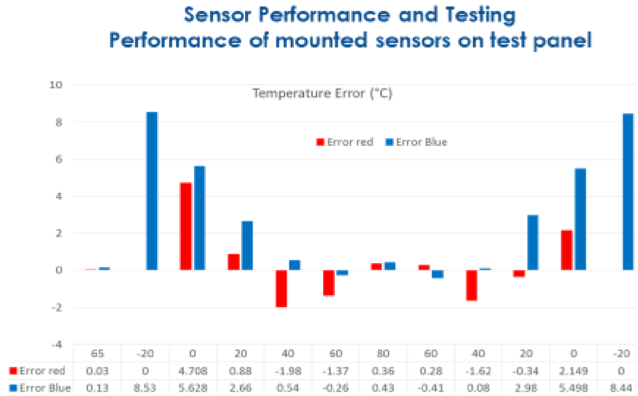

Figure 7: Temperature induced measurement error for two PM-DTG sensors in FOFRA

The flex was temperature cycled in an oven from -20°C to +80°C and the temperature error for two Polarization-Maintaining-Draw Tower Gratings (PM-DTGs) sensors was measured, shown in Figure 7. The hysteresis is expected to be due to the humidity effects on the coating. Other fiber coatings should be investigated to mitigate this effect.

5. SUMMARY AND OUTLOOK

There should be no doubt that fiber optics will obtain a greater share of data signaling in the space industry in the foreseeable future, and the advantages of FOFRA has been demonstrated to be of great benefit to telecommunication satellite and fiber optical sensing applications. A production setup with machinery has been developed.

It has been shown that it is possible to manufacture the product using materials with space experience and to route the fibers with high precision. The material composition needs to be verified by environmental tests with the parameters set by the end customers. Furthermore, repeatability of the production setup needs to be documented.

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