# DiaLink optical fiber connectors for rotating fiber links

**P. Bernasconi, S. Fantini**

Diamond SA, Via dei Patrizi 5, 6616 Losone, Switzerland
www.diamond-fo.com

*Abstract: The inertia of a few optical fiber connectors is evaluated to identify the configuration that is more suitable for applications that require rotating optical connections. The new DiaLink products represent the most promising option thanks to their compactness and light weight properties. The cylindrical symmetry and minimal footprint allows for a reduction of the inertia by a factor 15-20 compared to traditional E-2000*$^{TM}$ *and SC connectors.*

## 1 Introduction

The flourishing growth of fiber optics beyond the original telecom industry into other fast emerging fields has expanded significantly the requirements on optical fiber interfaces. Driven especially by optical sensors now deployed in the most diverse environments and for the most different tasks, the need of compact, lightweight optical connectors suitable for rotating assemblies is in high demand. Whether only half of the interface as in a rotary joint revolves or the optical joint is spinning like in various types of optical catheters, the mechanical and optical characteristics of the link has to be properly tuned to the specific application. The search for a universal solution to the constraints and requirements set by the industrial, medical, aeronautical, sensor, or metrology sectors is anything but straightforward.

In the following, two popular connector interfaces and a new emerging one are compared in order to evaluate their suitability for rotating environments in terms of mechanical and geometrical properties.

## 2 Rotating optical interfaces

A recurring issue with revolving parts is related to their stability under rotation. In most instances, a cylindrical symmetry in geometry and mass distribution is preferred. More and more frequently, small form factors and limited weight are also required especially for application in the medical and sensor fields. All this, of course, without loss of optical performance and, possibly, in compliance with the requirements imposed for example by sterile or strictly controlled clinical environments.

Historically, most optical fiber connectors have been developed for telecom purposes and, from there, other sectors have borrowed and adapted depending upon their specific needs. This is still done to leverage decades of technical development and to take advantage of the reduced prices offered by large-scale manufacturing of what has nowadays become a commodity product.

However, the priority lists in different application fields do not always match and many existing telecom solutions are not fully adequate when applied outside their original scope. For example, many popular connectors like FC, DIN (LSA), ST$^{TM}$, SMA or AVIM are not suitable because of their metal structures, which make them appreciably heavier than plastic counterparts such as, for example, SC, LC, E-2000$^{TM}$ or F-3000$^{TM}$ connectors. The choice is further limited if only push-pull options are considered at the expense of screw-on interfaces.

The purpose here is to identify a compact, lightweight fiber connector that does not induce or minimizes wobbling and unbalanced motions throughout eccentric rotations. We compare two connectors well-known in the telecom field, i.e. SC and E-2000$^{TM}$, and a DiaLink optical interface that was originally developed for fiber-to-the-home (FTTH) application but it is now adapting itself very effectively to the medical and sensor area.

### 2.1 DiaLink connectors

The DiaLink was born as a breakaway coupling device designed to safely unlock whenever submitted to sudden and excessive pulling forces. Built around a 1.25 mm ferrule, the male and the female portions of the connector can be easily and repeatedly mated through a push-pull locking mechanism. An enclosure designed to minimize the risk of contamination of the fiber end-faces also reduces the need for cleaning. The two sections can be interleaved by a transition adapter (also known as UGT) with a very similar structure, as shown in Fig. 1. This optional feature is often used as a sacrificial layer to protect one of the two sides from excessive wear and tear against mating with e.g. disposable counterparts.

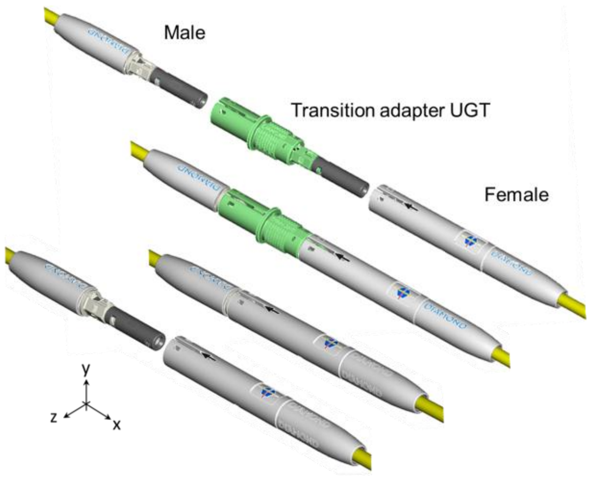

Fig.1: Male and female DiaLink connectors and full connector assemblies with and without transition adapter (from top to bottom).

All DiaLink elements have an almost perfect cylindrical symmetry with all relevant functional features confined within an outer shell of 5-mm diameter. When fully assembled the DiaLink connection systems are 71-mm and 55-mm long with and without UGT, respectively (see Table 1). In addition to a very small form factor, this kind of connectors also benefits from a very tiny mass, as shown in Table 2. The optical performances in terms of insertion loss (IL), return loss (RL), and repeatability compare well with the best connector solutions on the market [1]. The DiaLink connectors are also well suited for applications in medical environments since they are fully EtO-sterilization compatible.

## 2.2 E-2000™ connectors

The E-2000™ connector system has been developed to cover essentially all requirements of the telecom market compliantly with most telecom standards. Unlike the DiaLink, a full fiber connection consists of a three-part system, i.e. two connectors with integrated spring-loaded protection caps and a mating adapter. In Fig. 2 we can see that in this case as well the E-2000™ connectors can be separated by a matching UGT.

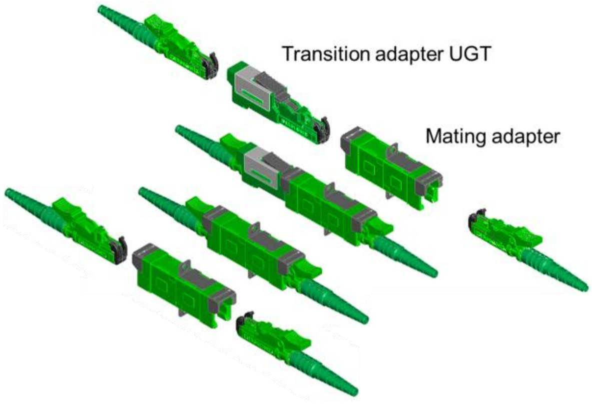

Fig.2: E-2000™ connector and full connector assemblies with and without transition adapter (from top to bottom).

The E-2000™ geometry with its more rectangular cross-section deviates appreciably from a cylinder. The length of a full assembly goes from approx. 133 mm to 110 mm with and without UGT, respectively with a maximum cross-section of 22 mm × 8.9 mm, as also reported in Table 1. Besides being bulkier than the DiaLink, the E-2000™ connector assembly is also appreciably heavier by almost a factor 5 (see Table 2).

In addition to the excellent optical performances [2], the EtO-compatibility and the IP 65 rating make E-2000™ components and assemblies suitable for biomedical markets and applications subject to sterile environmental conditions.

## 2.3 SC connectors

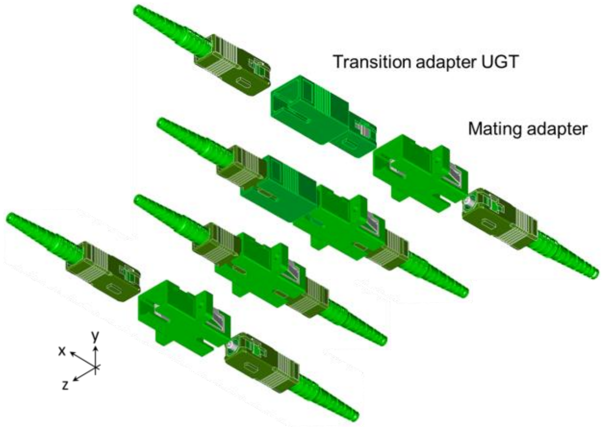

Fig.3: SC connector and full connector assemblies with and without transition adapter (from top to bottom).

The SC interface is another well-known telecom standard connector that has expanded its use to many other industrial and scientific fields. Like the E-2000™, the SC assemblies rely upon two connectors held together by a mating adapter and locked in place by a push-pull mechanism. The SC interfaces do not offer any mechanical protection to the ferrules' end-faces when disconnected. Similarly to the other connector options, there is a matching transition adapter UGT to be used as sacrificial layer.

The geometry of the SC assemblies is definitely more rectangular with dimensions essentially equivalent to the E-2000™ conterpart. In fact, as shown in Table 1, with a cross-section of 9.3 mm × 22 mm, the length of the total assembly with and without UGT amounts to 132 mm and 109 mm, respectively. In terms of weight, the SC assemblies are slightly lighter than the E-2000™ but still 4-5 times heavier than the DiaLink, as it can be verified in Table 2.

The optical performances are very close to the E-2000™ connectors [3].

## 3 Rotational properties

When it comes to the investigation of the dynamic properties of the connectors or connector assemblies, the inertia tensor is the physical quantity that provides an insight into the properties of the rigid bodies under rotation [4]. The moments of inertia are defined as

$$I_{ik} = \int \rho(x_i^2\delta_{ik} - x_i x_k)dV$$

where the integral is taken over the volume of the body of density $\rho$ and $\delta_{ik}$ represents the identity tensor taken in the coordinate system defined by $x_i$ ($i$ = 1,2,3). The magnitude of the tensor's elements and the analysis of their symmetry offer a first indication about how the connector's assembly behaves when spinning about its own principal axis or any other external one.

| | DiaLink | | E-2000™ | | SC | | Units |
|---|---|---|---|---|---|---|---|
| | Total assembly | | Total assembly | | Total assembly | | |
| | no UGT | with UGT | no UGT | with UGT | no UGT | with UGT | |
| Length | 54.9 | 71.4 | 109.8 | 132.8 | 109.3 | 132.4 | [mm] |
| Hight | ∅ 5.0 | ∅ 5.0 | 22.0 | 22.0 | 9.3 | 9.3 | |
| Width | | | 8.9 | 8.9 | 22.0 | 22.0 | |

**Table 1:** Maximum footprint of the DiaLink, E-2000™ and SC connector assemblies with and without transition adapters (UGT).

|  |  | DiaLink |  |  |  |  | E-2000$^{TM}$ |  |  |  |  | SC |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Connector |  | UGT | Total assembly |  | Connector | Adapter | UGT | Total assembly |  | Connector | Adapter | UGT | Total assembly |  | Units |
|  |  | male | female |  | no UGT | with UGT |  |  |  | no UGT | with UGT |  |  |  | no UGT | with UGT |  |
| Mass |  | 0.64 | 1.06 | 0.57 | 1.71 | 2.26 | 2.33 | 3.58 | 3.16 | 8.24 | 11.40 | 2.60 | 1.10 | 4.68 | 6.27 | 10.79 | [g] |
| Volume |  | 273 | 508 | 289 | 785 | 1070 | 1265 | 2157 | 1417 | 4686 | 6103 | 1512 | 433 | 1827 | 3464 | 5284 | [mm$^3$] |
| CM offset |  | 0.001 | 0.015 | 0.035 | 0.01 | 0.016 | 1.47 | 2.87 | 2.36 | 2.16 | 2.24 | 0.013 | 0.49 | 0.027 | 0.1 | 0.07 | [mm] |
| Moments of inertia | $I_{xx}$ | 1.54 | 3.13 | 1.41 | 4.67 | 6.07 | 22.7 | 101.1 | 48.4 | 149 | 196 | 22.7 | 20.6 | 68.2 | 66 | 134 | [g·mm$^2$] |
|  | $I_{yy}$ | 33.0 | 84.2 | 30.3 | 352 | 804 | 336 | 385 | 427 | 288 | 684 | 360 | 30 | 332 | 2610 | 6200 |  |
|  | $I_{zz}$ | 33.0 | 84.2 | 30.4 | 352 | 804 | 348 | 424 | 406 | 295 | 694 | 362 | 43 | 348 | 2630 | 6230 |  |
| Tilt angle |  | 0.00 | 0.06 | 0.40 | 0.51 | 0.43 | 0.68 | 0.88 | 7.12 | 0.13 | 0.17 | 0.00 | 6.59 | 0.32 | 0.08 | 0.08 | [deg] |

**Table 2:** Comparison among the relevant quantities related to the inertia of the DiaLink, E-2000$^{TM}$ and SC individual elements and complete connector assemblies with and without transition adapters (UGT). The tilt angle refers to the equatorial elevation of the inertia ellipsoid with respect to the plane enclosing the optical fiber (see Fig. 4).

For practical purposes, the initial coordinate system is chosen with the *x*-axis coincident with the fiber's core inside the connectors. The two other orthogonal axes are set to be parallel and perpendicular to the line defined by the conventional connector's alignment key.

A first quantity of interest is the offset of the assemblies' center of mass (CM) with respect to a rotation line along the *x*-axis. A small offset obviously reduces the centrifugal forces that a spinning connector exerts onto the surrounding structures and to the attached fiber cable. From the data summarized in Table 2, it can be appreciated that the DiaLink assembly provides, in addition to the smallest size and weight (Tables 1 and 2), the closest CM to the fiber's axis. The DiaLink's mass is in fact approximately 4-5 times smaller than the other two connector types regardless of the presence of the transition element UGT. It can then be readily concluded that this kind of connector accumulates the least amount of kinetic energy under rotation around its fiber's axis. Furthermore, this outcome is supported by considering the principal momentum of inertia related to a rotation about the *x*-axis: the DiaLink $I_{xx}$ tensor element is 15-20 times smaller than assemblies based on the E-2000$^{TM}$ or SC, with or without UGT. The resilience of the DiaLink geometry to mechanical effects that may lead to a detrimental wobbling of the assembly compared to the other connector types is quite important.

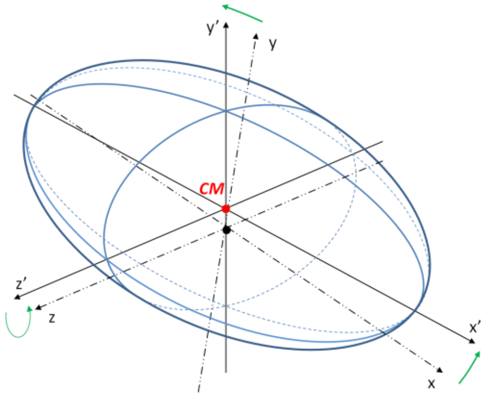

Fig.4 Inertia ellipsoid oriented along the *xyz* coordinate system with the *x*-axis coincident with the fiber. The main ellipsoid axes *x'y'z'* originate from in the assembly's center of mass (CM). The *x'y'z'* system is offset with respect to the original coordinate system and slightly rotated about the fiber's *z*-axis.

The trivial observation that the DiaLink possesses an almost perfect cylindrical symmetry is confirmed by the two other momentum elements $I_{yy}$ and $I_{zz}$. These are essentially identical proving that the mass is very homogeneously distributed about the optical fiber. Table 2 also reports how the inertia ellipsoid is oriented with respect to the *x*-axis. The DiaLink's ellipsoid is tilted with respect to the equatorial plane by a slightly larger angle compared to the E-2000$^{TM}$ and SC counterparts. However, this is not a major concern for the following reasons. Due to the small mass of the DiaLink elements, any tiny asymmetry in the mass distribution magnifies the tilt of the inertia ellipsoid. In this case the tilt of the equatorial plane is caused by the vertically unbalanced features used to align male and female connectors. If necessary, this deviation can be easily rebalanced by redistributing the mass through a minor modification of the outer casing without any constraints since all relevant structures reside inside the external protection shell.

## 4 Conclusions

A first mechanical analysis about three fiber connector assemblies reveals that the DiaLink is more suitable for rotating applications compared to E-2000$^{TM}$ or SC solutions. The advantage resides in an almost perfectly cylindrical structure of the DiaLink connectors and a greater homogeneity of their mass distribution around the rotation axis along the fiber. Another important role is played by the tiny mass of the DiaLink assemblies that amounts to only a fraction of the other E-2000$^{TM}$ or SC connectors. All this yields to a reduction of the inertia of the full assemblies by more than an order of magnitude without affecting the optical performance.

For all functional features are encapsulated by its outer shell, the DiaLink is very flexible and adaptable since all external modifications will have little or no impact on the push-pull connecting mechanism and performance. Lastly, the compatibility with EtO-sterilization processes makes this connector an attractive choice for medical and sensor applications.

## References

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