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Evolution of optical fibre cabling components at CERN: Performance and technology trends analysis

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A B S T R A C T

CERN optical fibre infrastructure has been growing constantly over the past decade due to ever increasing connectivity demands. The provisioning plan and fibre installation of this vast laboratory is performed by Fibre Optics and Cabling Section at Engineering Department. In this paper we analyze the procurement data for essential fibre cabling components during a five-year interval to extract the existing trends and anticipate future directions. The analysis predicts high contribution of LC connector and an increasing usage of multi-fibre connectors. It is foreseen that single-mode fibres become the main fibre type for mid and long-range installations while air blowing would be the major installation technique. Performance assessment of various connectors shows that the expanded beam ferrule is favored for emerging on-board optical interconnections thanks to its scalable density and stable return-loss.

1. Introduction

The European Organization for Nuclear Research (CERN), is home to a large accelerator complex, thereunder the Large Hadron Collider (LHC). Every year a substantial volume of optical fibre cabling components (i.e. fibre cables, connectors, etc.) are supplied through an industrial support contract and installed under the responsibility of the Fibre Optics and Cabling Section (FCS) in Engineering Department, Electrical Engineering Group [1].

CERN optical fibre installations cover a wide range of connectivity applications. Apart from the internet connection network, several other services employ extensive fibre installations. For example, the accelerator Timing and Synchronization system implements a modified GPON standard which requires a substantial fibre connectivity [2]. Another example is the Electrical Network Control system, which constantly measures vital control parameters of the power distribution systems (equipment alarms and temperature) through a specific fibre infrastructure [3]. Security, Surveillance and Access Control systems have recently requested a considerable volume of fibre connectivity due to a major hardware upgrade. Above all, with new Data Centers (DC) under design and construction, the DC interconnect is expected to require a significant fibre installation [4,5].

Transmitting such a high data volume through the fibre infrastructure necessitates regular provisioning and upgrade plans [6]. One insightful approach for such planning is to study the trend of past deployed technology. In fact, analyzing the procurement data in recent years can reveal evolution of various connectivity solutions. In particular, such analysis shows the direction of dominant solutions which in turn can be used for directed market surveys and resource allocation in the forthcoming installations.

On the other hand, once the fibre cabling components are installed, their reliability becomes vital for the accelerator harsh environment through their role in conveying critical data. Indeed any major defect in optical components can impose an unintended downtime, leading to a considerable maintenance cost [7]. Therefore, considering the complex procurement process, the reliability assurance of these components necessitates special provisioning which involves systematic performance monitoring of selected samples.

The first part of this paper studies the evolution of various components installed by FCS during a five-year interval. These components cover the major passive elements of structured fibre cabling including conventional and microduct fibre cables, pre-terminated fibre cables and optical connectors. The analysis results will be used to predict the direction of optical fibre installation in various sectors and provide valuable feedback for future procurement and planning activities.

The second part of the paper is dedicated to statistical performance analysis of the procured components in the same time interval with the focus on connector Insertion Loss (IL) and Return Loss (RL). The analysis results can be used to monitor the essential quality criteria and to provide an assessment benchmark among different connector types.

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Table 1
Total number of procured connectors during 2012–2016.

Year	2012	2013	2014	2015	2016
Count	14.5 k	34.8 k	28.1 k	12 k	5 k

2. Installation components & techniques

In this section we analyze the evolution of the CERN optical fibre infrastructure during a five-year interval between January 2012 and December 2016. This study is carried out on different categories of components followed by a market trend analysis, to compare CERN approach with the dominant market directions.

2.1. Optical fibre connectors

The optical fibre connectors could be one of the standard types among Subscriber Connector (SC) [8], Straight Tip (ST) [9], Lucent Connector (LC) [10], Ferrule Connector (FC) [11], LSH (known as E2000) [12] and Multi-fibre Push-on/Push-off (MPO) [13]. Note that the connectors that are analyzed in this paper are produced from various manufacturers and are assembled on fibre cables prior to delivery at CERN (pre-terminated cables).

Table 1 denotes the total number of procured connectors (of all types) during 2012–2016. A peak can be observed in 2013 and 2014 which is associated to the Long Shutdown 1 (LS1) period. In this period the accelerator operation was stopped for major upgrades which raised the procurement volume of fibre cabling components [14]. Therefore, to cancel out the effect of variable annual volume, we normalize all the forthcoming data to the annual sum of each category.

Fig. 1(a) shows the percentage of various procured connectors after normalizing to the total connector count given by Table 1. According to this figure ST connector has average usage of 12.4% over the five years. This connector is one of the oldest designs which uses a 2.5 mm ferrule for multi-mode (MM) optical fibres [15]. FC connector has the lowest usage at CERN with 3.3% overall average. This connector was introduced as an upgrade of ST since it isolates cable tension from the ferrule and provides the possibility of angled polishing [15].

Among single fibre connectors, SC has the second lowest usage with 3.7% overall average. This connector was initially developed to provide an easier mating condition compared to FC by eliminating the screwing action as well as reducing the connector price by molding manufacturing process rather than machining [15]. However, the E2000 connector which was developed afterward, outperformed SC through its smaller footprint, the integrated dust cap and the special latch mechanism [15]. Therefore, this connector became the standard type for intra-rack interconnection of SM fibres in CERN distribution points.

Fig. 1(a) shows that E2000 connector is the second most abundant type with a stable average of 29% over the five years. The LC connector was later developed with a retaining tab mechanism and 1.25 mm ferrule to further improve the connector density on the patch panels [15]. This connector which generally comes in duplex configuration is extensively used for connecting optical transceivers which require a fibre pair. As shown in Fig. 1(a), LC is the most frequent connector with a noticeable average of 46%.

Multi-fibre connector is another technology which is designed for high density interconnections. Among various types of multi-fibre connectors, CERN chose MPO as it is more adopted for parallel transmission thanks to the high fibre count, high connection performance and ease of handling [16]. Despite taking only 8.0% of all types, MPO provides a substantial fibre connectivity load. Connectivity count is defined as single connectivity for single-fibre connector and several connectivities for multi-fibre connectors (e.g. 12 connectivity for 12-fibre MPO). Fig. 1(b) depicts the connectivity percentage for various connectors, showing a considerable contribution of MPO (average 42%).

Fig. 1 can be also used to track the dynamics of using various connectors during the past years to predict their contribution in the following years. For example, LC and E2000 connectors show a very stable usage whereas the use of ST and FC connectors undergo a gradual decrease in the same period. Noticeably, MPO experiences a substantial growth in this interval, from 1% in 2012 to 12% in 2016. MPO percentage will likely exceed 20% of the annual volume in 2017 which corresponds to more than 70% of the connectivity load.

These trends can be compared to the global fibre connector market segmented on campus networks. Market trend shows the demand for higher data transmission rate is persuading network planners to adopt high density parallel links using LC and MPO connectors [17]. To cope with this trend, FCS has started investigating more recent multi-fibre solutions. Accordingly, in Section 3.2 we study the performance of Expanded Beam (EB) multi-fibre connector as a promising solution for ultra-high density multi-fibre interconnections.

2.2. Non-terminated fibre cables

We define non-terminated fibre cables as a bundle of buffered fibres inside a cable sheath without connectors at both extremities. Non-terminated cables can be either *conventional fibre cables* with reinforced strength elements or *microduct fibre cables*, with a light weight, low friction outer sheath. In traditional cabling, conventional fibre cables (loose tubes, ribbon or etc.), are pulled into conduits and ducts [18]. The microduct fibre cables are instead installed by Air Blowing (AB) into the existing microducts [15].

Essentially, the initial installation costs of AB is roughly 2.5 higher compared to cable pulling. However, from the design point of view instead of installing a large amount of dark fibres for future growth, AB allows for deploying the cable tube and waiting for the time the fibres are required to be blown. In general AB allocates less installation resources in terms of number of technicians and installation time per unit length. However, the exclusive benefit of AB is routing the fibre without any need to directly access the entire path [19]. This property is extremely important at CERN as considerable fibre installations are located in high radioactive environment. Such areas execute special

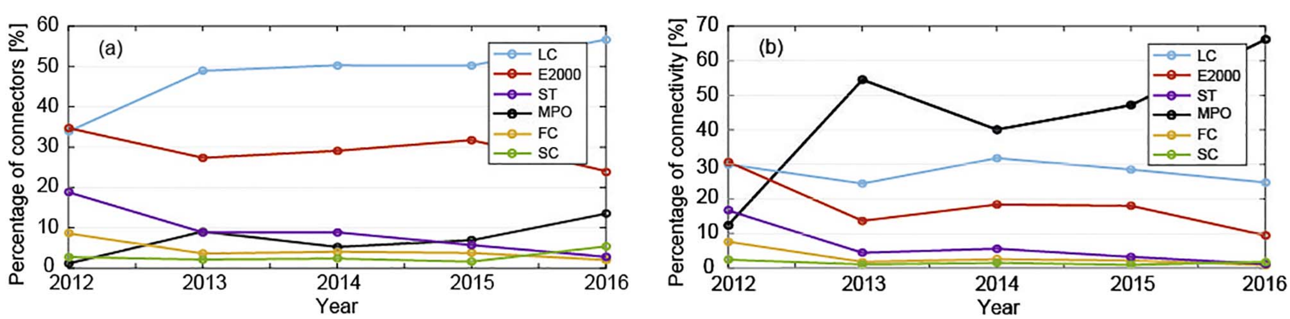

Fig. 1. Percentage of connector count (a) and connectivity count (b) for various connectors procured during 2012–2016.