CONNECTING FIBER OPTICS

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Abstract. This paper presents typical connectors for fiber optics and discusses their advantages and disadvantages. Light traveling inside a fiber behaves quite differently from electricity traveling on a wire, except if one looks at both of these phenomena only as an input-output connecting “black box.” The light in a fiber is a wave and the fiber is a waveguide. Any imperfections or irregularities when interconnecting the fibers are potential sources both for power losses and for signal-to-noise degradations. We shall start with some notations on communications system with fiber optics, and we will afterwards focus on various types of connectors and their main characteristics.

1. FIBER OPTICS SYSTEMS

The development of fibers and devices for optical communications began in the early 1960s and is still pursued strongly today. The major changes happened in the 1980s. During this decade optical communication in public communication networks developed from the status of a curiosity into being the dominant technology [1].

An optical communication system is formed by a transmitter, a fiber optic (usual cables of fibers optic), and a receiver (see figure 1).

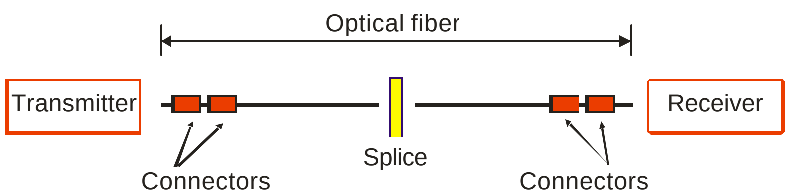
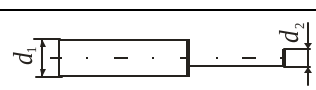
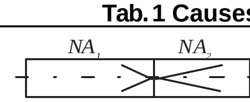
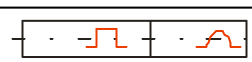
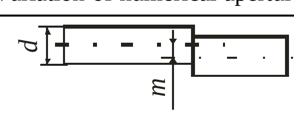
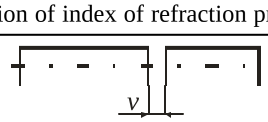
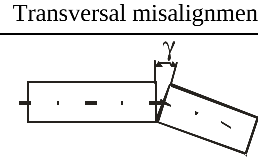
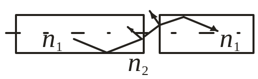
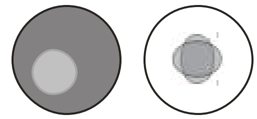


Fig. 1. Optical communication system

The most critical factor of a fiber optic connector (or splice) is the alignment. An ideal connection should perfectly align the fibers, especially the light carrying cores, so that the joint is transparent with no loss of optical energy. Unfortunately, both the fiber and connector are subject to manufacturing tolerances that create less than perfect alignments. Some of the causes of misalignment are enumerated in table 1 [2].

Tab. 1 Causes of misalignment

 Variations of fibers diameters	 Variation of numerical apertures
 Variation of index of refraction profiles.	 Transversal misalignment
 Axial gap	 Angular misalignment

 Surface reflections	 Concentricity & Ellipticity

The difference between the axis of the core and the axis of the cladding is expressed as the "concentricity" of the fiber. This means that unless one does something to align the cores simultaneously with making the connection, there will be a (random) misalignment, and hence a loss, imposed by the concentricity error [3]. The major improvements in optical transmission was due generally to better fiber manufacturing as much as to better connectors and connection techniques.

2. CONNECTORS FOR FIBER OPTICS

Connectors hold the fiber cable ends in exact position and butt them together under soft pressure to obtain a good connection. This process depends on the precision to which connectors can be machined [4]. Most mechanical devices are machined to tolerances on the order of tenths of a millimeter. Fiber tolerances are around one micron. This means that connectors have to be about 100 times more accurately machined than most mechanical "things." It follows that connectors are difficult to manufacture and even harder to fit, resulting in relatively high costs.

The characteristics of fiber cables vary widely due to the different environments where they are deployed and the requirements they must fulfill. Fiber cables are made to suit the application they are to perform, and there are hundreds (perhaps even thousands) of types. Figure 2 shows a few examples.

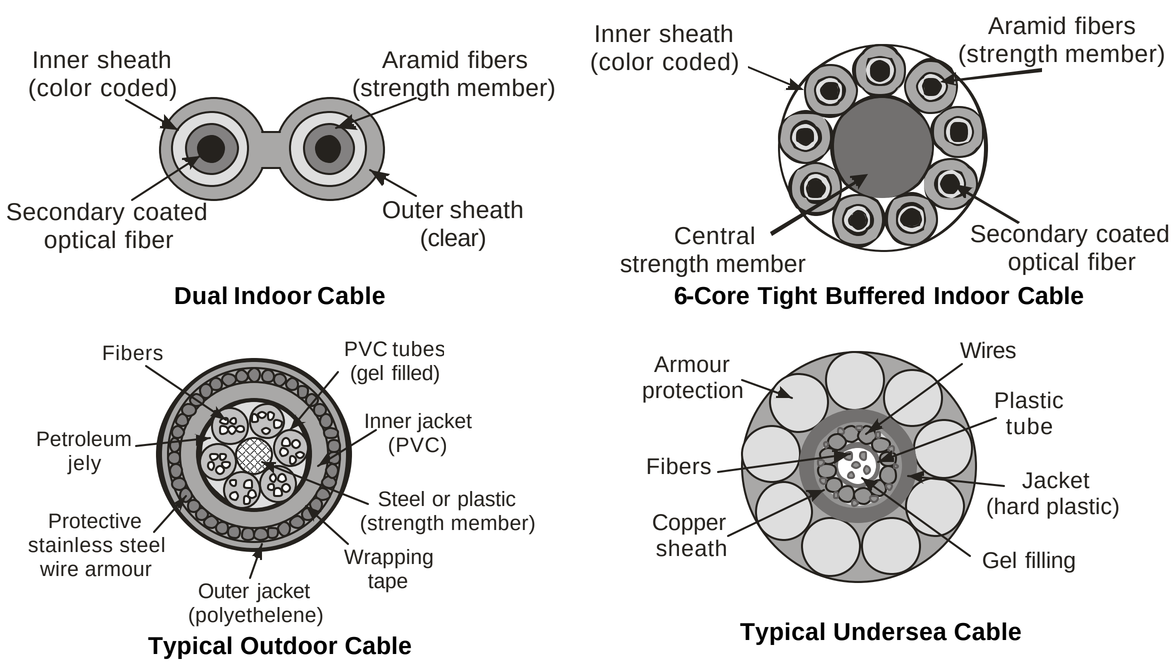
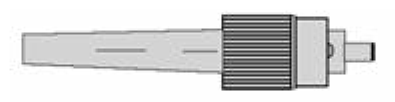
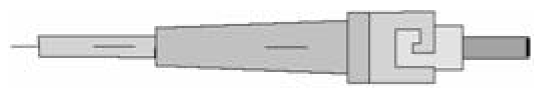
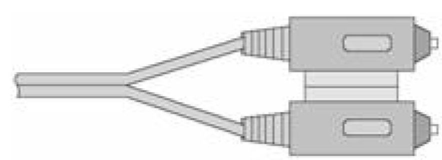


Fig. 2. Typical fiber optic cables [3]

When inserting an active fiber optic component into a fiber optic connector, the amount of power that can be launched into the cable depends significantly on the alignment of the light from the transmitter to the end of the fiber optic cable. The active spot of light is more intense in the center of the connector and any misalignment can drastically change the amount of light released into the cable. It is very important to minimize any air gap between the fiber optic transmitter and the end of a fiber optic cable. The process for a good assembly and alignment of transmitter into a fiber optic connector is quite evolved, and requires specific expensive devices [4].

Connector manufacturers use protective sockets into which the cable connectors can be inserted and locked. These protective sockets have a fitting to allow them to be pulled through a cable duct whilst protecting the fiber cable. Connectors for multi-mode (MM) and single-mode (SM) fibers are generally different but the most popular connectors come in versions for either type. Table 3 shows some of the most usual types of connectors.

Tab. 3 Typical connector types [3]

Symbol	Schematic Drawing
FC/PC	
ST	
SC - Duplex	

Both fibers and connectors are manufactured to extremely precise tolerances, which help in aligning fibers mechanically. While there are other methods, such as using lenses to collimate and focus light, the most widespread method is to manufacture a highly precise placed hole in a precisely toleranced ferrule [5, 6, 7]. Because connector size is a primary factor in port density, cable connectors continue to get smaller. Most of this gain comes from the use of smaller ferrules. The newer connectors (MU and LC) use a 1.25 mm diameter ferrule, exactly half the size of a 2.5 mm diameter ferrule used in traditional FC, ST and SC connectors (see table 3).

Here is a list of standardized connectors (from a quite large selection range)

- *LC Connectors* utilize a 1.25-mm ceramic ferrule and the versatile pull-proof latching mechanism. Available for SM, MM, simplex and duplex versions, they offer low insertion loss, low back reflectance and repeatable performance.
- *MU Connectors* are one half the size of the standard SC connector, and are sometimes referred to as *mini-SC*. Featuring a push-pull latching mechanism similar to the SC, the MU connector is easy to connect and disconnect.
- *SC Connectors* emerged in the early 1990s as the general purpose connectors. SC connectors use a 2.5 mm ferrule, push-pull locking mechanism and pull-proof design that prevent a slight pull on the cable from pulling the ferrule out of its optical contact.
- *ST Connectors* use quick release bayonet couplings. A key ensures consistent, repeatable mating with the coupling bushing. They are available in a range of

variations including ceramic, polymer or stainless steel ferrules and either epoxy or epoxyless style termination.

- *FC Connectors* are used mainly in the telecommunications industry. They use threaded couplings and 2.5 mm ferrules. Some variations of the connector use tunable keying to achieve the lowest loss. Tuning allows one ferrule to be rotated in relation to the other to minimize losses.
- *FDDI-MIC Connectors and ESCON Connectors*, (as duplex connectors) use a side-latching mechanism and two 2.5 mm ferrules, as well as a fixed protective shroud to protect the ferrules. The connectors can be keyed according to fiber distributed data interface (FDDI) specifications, but can also be used for non-FDDI applications. ESCON connectors, are similar to the FDDI-MIC connectors, but use retractable shrouds.
- *Plastic Fiber Connectors* are available at low cost for fast termination to the cable. Most connectors require no epoxy, allow end finish to be achieved by trimming the fiber with a hot knife, and require little or no polishing. Performance is in the 1...3 dB range. Many plastic fiber connectors incorporate transmitters and detectors directly as a means of reducing cost, simplifying the system and providing standardized parts.
- *MT-RJ Connectors* are two-fiber connectors that resemble a standard telephone plug. The resemblance is intentional, as the connector is aimed at replacing the ST and SC types in wiring closets and at the desk. The connector fits in the same cutout as an RJ-45 telephone jack, allowing fiber to be installed in network equipment, patch panels and wall plates without space penalties. The connector features a single, snagless latch. Rather than the typical fiber mating scheme that uses two plugs joined in a coupling adapter, the MT-RJ connector offers a true plug to-receptacle mating technique.

The signal loss experienced at a connector or splice is far from a fixed or predictable amount. This raises major problems when designing and deploying fiber optics, as the measured losses in connectors vary considerably from one another.

3. CONCLUSIONS

The widespread use of fiber optics for (data) communication has pushed the industry to develop diversified connecting components on an yearly basis. Standardization of such (telecommunication) components has taken place in parallel. Obviously, connectors are the most important not only due to their basic function of "connecting" (and also of being interchangeable), but mostly due to their very demanding technical parameters. Such connectors have to respond to the acute need for keeping the output signal above a minimum threshold, hence minimizing the (power/energy) losses of the input signal over the system. An additional challenge (for the manufacturers) is raised by the continuous miniaturization trend dictated by the need to integrate more devices (in parallel) for satisfying the growing bandwidth needs.

All of these aspects should be weighted together with economical/financial constraints. Obviously, very high performance optical connections are possible, but require not only expensive connectors but also highly specialized equipment and workers to install and service them. For achieving an optimum, the fabrication and operation tolerances should be very carefully tuned.

This paper has shortly enumerated some of the most widely used fiber optics connectors (and their characteristics). We have also tried to highlight the importance played by connectors in the chain of devices needed for any optical communication. Like with other chains, it is the weakest link (by design, by implementation, or by assembly/installation) that limits the overall performance of the system. That is why the implementation of an optical communication system requires not only a clear overall view of the system (with a deep understanding of the performances to be achieved), but also a careful selection of all the assembling components.

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