Automated Inspection and Cleaning of Fiber Optic Cable Connections
- An Industry Breakthrough -

Abstract

Fiber optics cabling, a $5.9 billion industry, is the core of today's worldwide data communication networks and is the predominant media type for mission-critical data center links within four major categories:

- Military/Aerospace
- Telecom
- Datacom
- Cable Manufacture/Assembly

Optical fibers are long, thin strands of very pure glass about the diameter of a human hair that have been arranged in bundles that form fiber optic cables. Light signals that have been converted from electronic signals are transmitted through the fiber optic cables over long distances for Telecom applications and over shorter distances for Datacom applications.

As network speeds, transmission distances, and bandwidth demands continue to increase, it becomes more critical that the attenuation (losses) through fiber optic cables be lower than ever before. Although there are many factors that contribute to these losses, it is the losses attributed to the variability of fiber optic inter-connections that can be costly due to fiber optic under-performance and/or failure rates.

Reducing these losses can only be achieved with stringent manufacturing procedures that incorporate inspection and cleaning protocols of the fiber optic cable connections up to, and including, final installation and system maintenance or, while making changes or system upgrades.

This paper examines the protocols and commercially available equipment that is currently being utilized for the inspection and cleaning of fiber optic connectors and adapters. This paper also looks at latest innovations and technologies that enable the transmission of ever increasing data rates while at the same time reduce manufacturing and operating costs.

The Challenge

Just as an electronic connector provides a pluggable connection between electronic circuits, a fiber optic connector provides an optical one. The challenge is joining a fiber to a transmitter, receiver or, another fiber with the lowest loss of optical power across the joint.

Any contamination in the fiber connection can cause failure of the component or failure of an entire system. Even microscopic dust particles can cause a variety of problems for optical connections. A particle that partially or completely blocks the core can increase the insertion loss above design limits or generate strong back reflections which can cause instability in the laser system. Dust particles trapped between two fiber end faces can scratch the glass surfaces. Even if a particle is only situated on the cladding or the edge of the end face, it can cause an air gap or misalignment between the fiber cores which significantly degrades the optical signal.
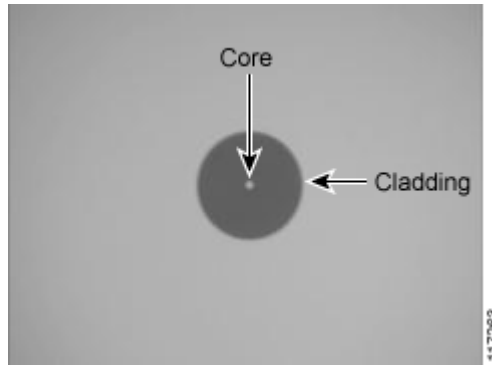
Figure 1 *Fiber optic end face with core diameter less than 10 micrometers (.00039 inch) and a cladding diameter of 25 micrometers (.00098 inch)*
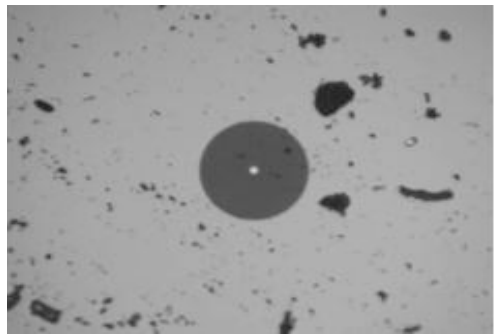

Figure 2 *The same fiber optic end face at 200x magnification with dust particles spread across the surface of the end face that will cause transmission losses or failures if not removed.*

A 9-micrometer speck (0.00035 inches) is still too small to see without a microscope, but it can completely block the fiber core. Smaller particles are of concern as they can cause partial blockage of light.

Proper inspection and cleaning of fiber optic connectors can save industry millions of dollars annually. Contamination of connector end faces in the form of something as simple as dust particles or fingerprints can change light propagation through the fiber resulting in degradation of device performance and causing data errors. To avoid this, it is common practice to clean and test the fiber optic endface prior to assembly which is an added cost to the initial manufacturing of the cable assembly. Although there are industry standards for connector cleanliness, devices can be either over-cleaned, which consumes manpower and materials, or under-cleaned, which can lead to expensive rework and/or failure in the field.

Endface scratches cannot be cleaned off and may not be detrimental to the fiber optic performance. However, if the scratches are deep and cross the fiber-optic core they can cause signal loss and in such cases, the fiber would need to be replaced or re-polished

Appendix A provides sample images of various levels and types of endface contamination and scratches.

Current Practices for Single Fiber Endface Inspection

A fiberscope is a customized microscope used to inspect optical fiber enfaces. Commercially available handheld fiberscopes are typically 200x magnification and in some cases ranging to 400x magnification or even higher. Adapters are provided to properly inspect the endface of a variety of connector types.

Portable hand-held fiberscopes shown in Figures 3 and 4 are in the $2K price range. They are designed to enable field technicians to quickly inspect individual fiber optic endfaces. In most cases, the Pass/Fail determination is a subjective one based on the technician's interpretation of the image for acceptability of the "cleanliness" of the end faces. For multi-pin connectors, the technician can only inspect one endface at a time and needs to manually scroll from endface to endface, which is a time-consuming and potentially error prone process.
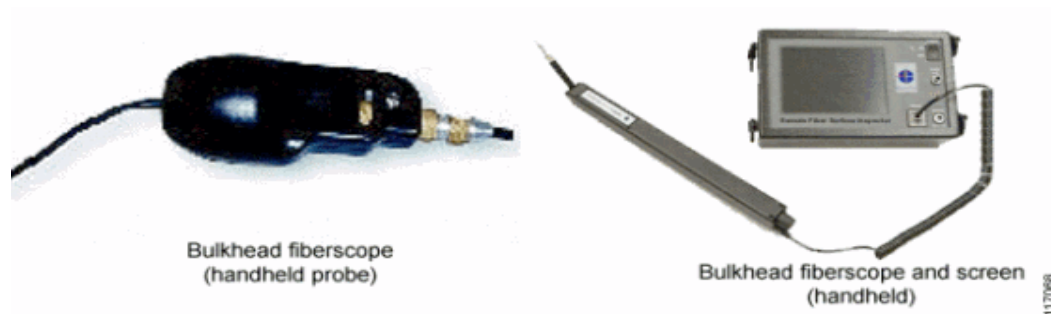

Bulkhead fiberscope
(handheld probe)

Bulkhead fiberscope and screen
(handheld)

Figure 3 *Two types of handheld fiberscopes (Photos courtesy of Fluke Network)*

Figure 4 *Fiber video inspection probe microscope and HD3 Display*
(Photo courtesy of Viavi)

Handheld fiberscopes are designed to also inspect connectors in a bulkhead, backplane, or receptacle port as shown in Figure 5 and provide 200x or 400x total magnification displayed on a video monitor. Separate adapters are required to properly inspect each connector type with good availability for the most common types.

Figure 5 *Handheld probe inserted into a bulkhead connection*
(Photo courtesy of Fluke Network)

Automated Inspection for Multi-Fiber Connectors
Handheld fiberscopes as described above are utilized for quick basic troubleshooting of single ferrule connectors with up to 72 fibers, with 12 and 24 fiber versions being the most common. At this level, labor is intensive which translates to cost, a major issue in any setting. The FastMT, shown in Figure 6 below, is an automated fiberscope provided by FiberQA, LLC that enables the rapid inspection of multi fiber connectors during the process of manufacturing, at the installation site by the end user and, during field maintenance that may be required thereafter.

The FastMT automatically inspects multi-fiber ferrules to magnifications of 200x and 400x. It contains software for segmenting the image into individual fibers, analyzing for defects, comparison against limits for Pass/Fail, and archiving all pertinent information for future reference. After initial set-up, the operator plugs the connector under test into the FastMT which automatically inspects all end faces with one set-up and provides on-screen pass/fail results. If any fiber fails, the entire connector fails and the individual endfaces requiring cleaning are quickly identified and the operator hand cleans each of them and reconnects to the FastMT for re-inspection. The FastMT is designed to inspect one multi-fiber ferrule or connector at a time.

Figure 6 *FastMT automatic fiberscope (Photos courtesy of FiberQA)*

Current Practices for Connector Endface Cleaning
International Electrotechnical Commission (IEC) provides industry standard IEC 61300-3-35, Edition 2 (released version published in June 2015)[1] that describes methods for quantitatively assessing the quality and cleanliness of a polished fiber optic endface. In general, the methods

described in this standard apply to 125µm cladding fibers contained within a ferrule and intended for use with sources of ≤ 2 W of input power.

Other contributors to these industry standards include iNEMI, SAE, TIA, ARINC, IPC, and IEEE.

Figure 7 *The contaminated endface (left) shown in this fiberscopic image is cleaned with a cassette type hand cleaner(center) and, when re-inspected, is found to be clean (right). (Photo courtesy of Photonics Spectra June 2004) (2)*

Automated Inspection and Cleaning

For large numbers of fiber optic cables assemblies, FiberQA offers the Automated Vision Inspection Tool (AVIT) product line that includes automatic inspection and cleaning of connectors. AVIT is a family of products, described below, that are designed for a broad range of users including cable manufacturers, quality control at installation sites and field maintenance.

The AVIT-2020 and AVIT-DT models are stationary workstations used in cable and board assembly houses for inspection and cleaning of high volumes of connectors.

The most recent additions to the AVIT product line are AVIT-BP and AVIT-RH. Both models are portable and are designed to access connectors within highly confined spaces such as found in aircraft, ships, submarines, UAV's (drones.) etc. Built-in robotics and software reduce manual labor costs while, at the same time, minimize the risk of damaging expensive connectors.

In addition to utilizing the same processing as the FastMT fiberscope, AVIT adds five additional capabilities:

1) Multiple ferrule/connector inspection

2) Integrated cleaning and re-inspection

3) Selection of pre-loaded test specifications, which may also be modified by customer's test engineering personnel, to ensure consistent testing throughout the supply chain.

4) Enables the operator to pre-set the maximum number of inspect/clean cycles before the part is ultimately failed which improves efficiency.

5) All results are fully archivable

Available AVIT models:

1. AVIT-2020, was the first automated inspection system on the market over 12 years ago, includes a 20" x 20" inspection window that manages board level inspection and cleaning

2. AVIT-DT - (desktop) is a smaller desktop version of the inspection and cleaning system, with a 5" x 5" inspection window.

3. AVIT-CH – (chassis) inspects and cleans the optical blind mate-able connectors on a backplane while installed inside a chassis. The camera and cleaner move from board to board and inspect all fibers.

4. AVIT-BP – (backplane) is a model designed to be installed into a single slot to inspect and clean blind mate connectors on the backplane of the chassis.

5. AVIT-RH – (remote head) is a model probe-style inspection system that attaches to circular receptacles and plugs with either MT or single fiber ferrules. This unit can automatically clean single fiber ferrules using specially designed cleaner cartridges.
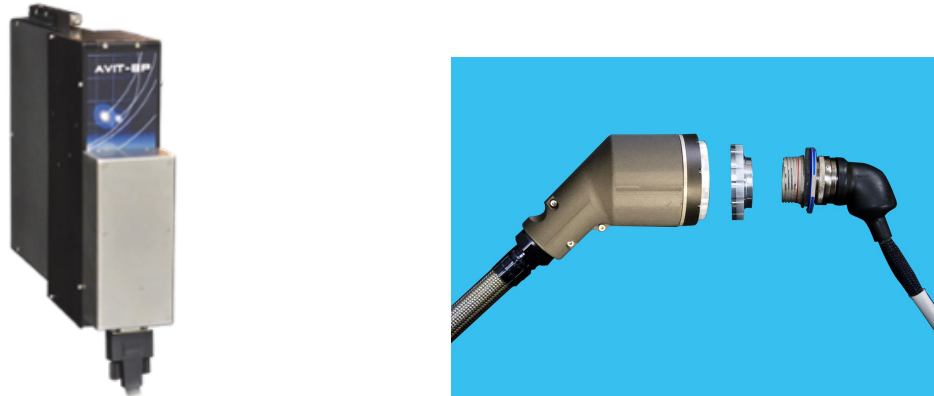
Figure 8 AVIT-BP (left) and RH (right)

Looking Ahead

The fiber optics communications industry is an ever evolving one. The growth experienced by the industry has been enormous this past decade and it appears that this will continue as shown in Appendix B.

There is still much work to be done to support the need for faster data rates, advanced switching techniques and, more intelligent network architectures that can automatically change dynamically in response to traffic patterns and at the same time be cost efficient. The trend is expected to continue in the future as breakthroughs already attained in the laboratory will be extended to practical deployment, thereby leading to a new generation in fiber optics communications. [3] These developments will create an ongoing demand for development of new and improved fiberscope technology with a focus on the ever-increasing need for the efficiency of fiber optic connector inspection and cleaning that will reduce both labor costs and, ultimately, system downtime.

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Appendix A

Sample Images of Various Contamination Conditions
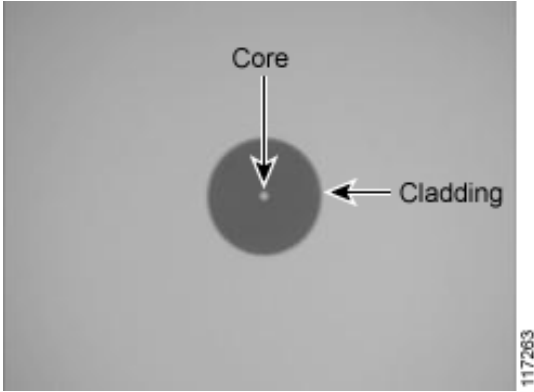*(courtesy of Cisco Systems Inc)*

Figure 1 a clean single mode ceramic endface at 200x magnification. Note: Sometimes the core is not illuminated.
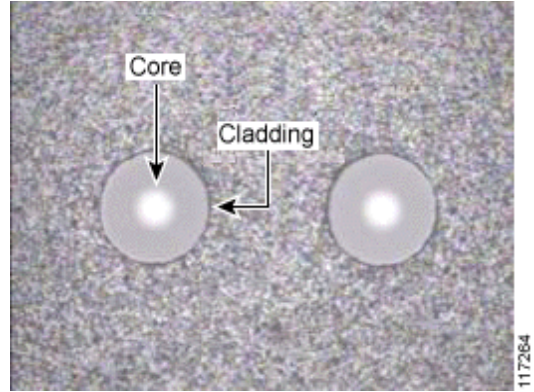

Figure 2 a clean multimode MT connector. Notice that there is a small amount of acceptable shadowing along the edge of the cladding.
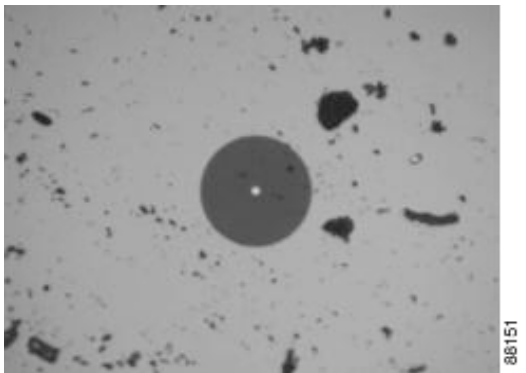

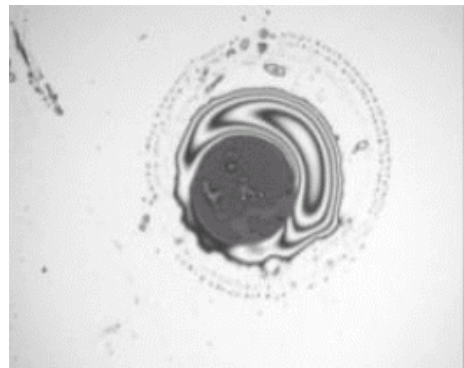Figure 3 a connector with dust particles spread across the surface of the endface that needs cleaning.

Figure 4 a connector with liquid contamination that needs cleaning (example 1)
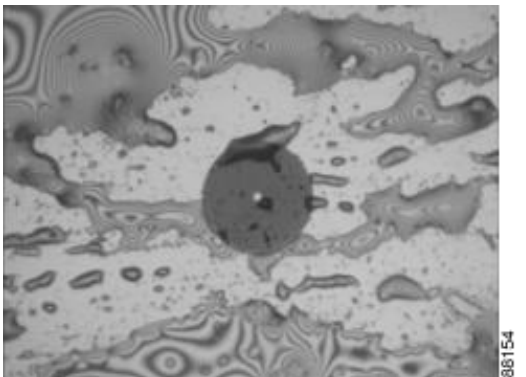
Figure 5 shows a connector with liquid contamination that needs cleaning (example 2)
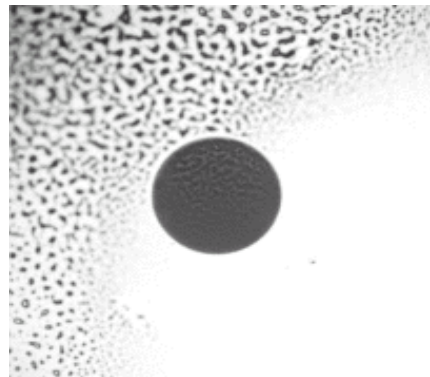
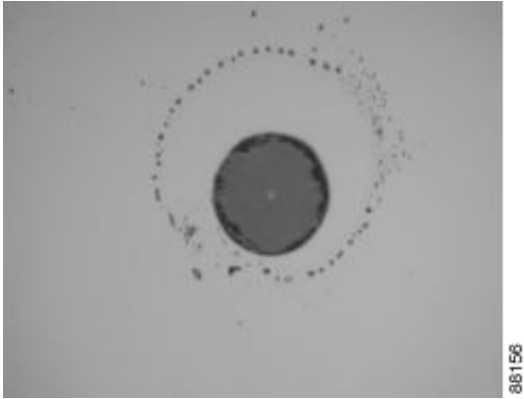Figure 6 a connector with alcohol residue that needs cleaning.

Figure 7 a connector with small droplets of liquid contamination that needs cleaning.
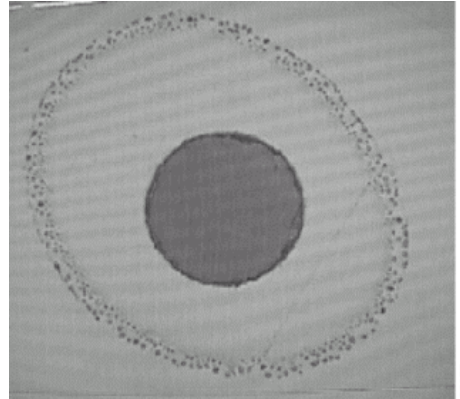

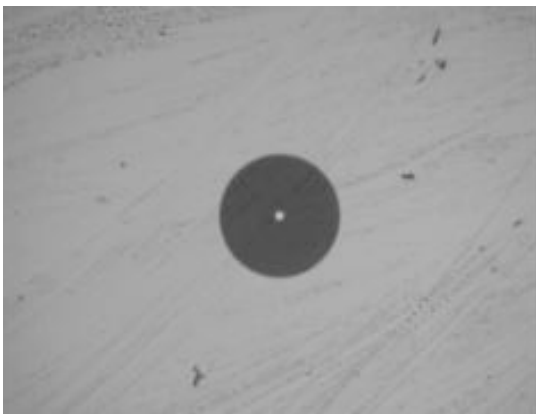Figure 8 a connector with a dry residue that needs cleaning.

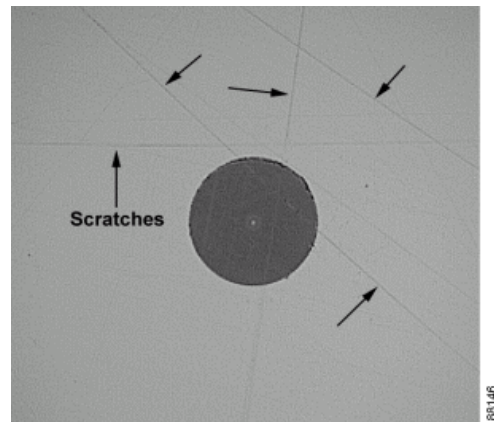Figure 9 a connector with an oil residue that needs cleaning.

Figure 10 a connector with scratches. These scratches are not detrimental to the endface and does not clean off. But, deep scratches that appear to cross the fiber-optic core can cause signal loss.
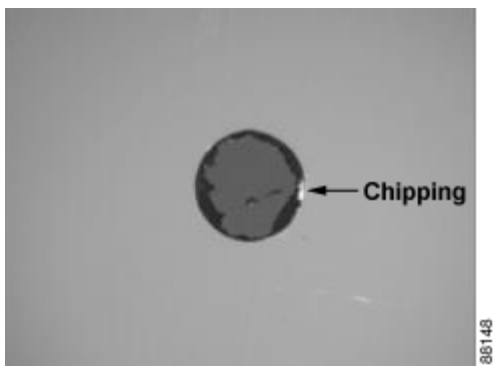

Figure 11 a connector with damage to the cladding. Cleaning cannot remove damaged cladding. A small amount of epoxy around the cladding is allowable, but this shows excessive epoxy around the cladding that does not clean off. This connector must be replaced
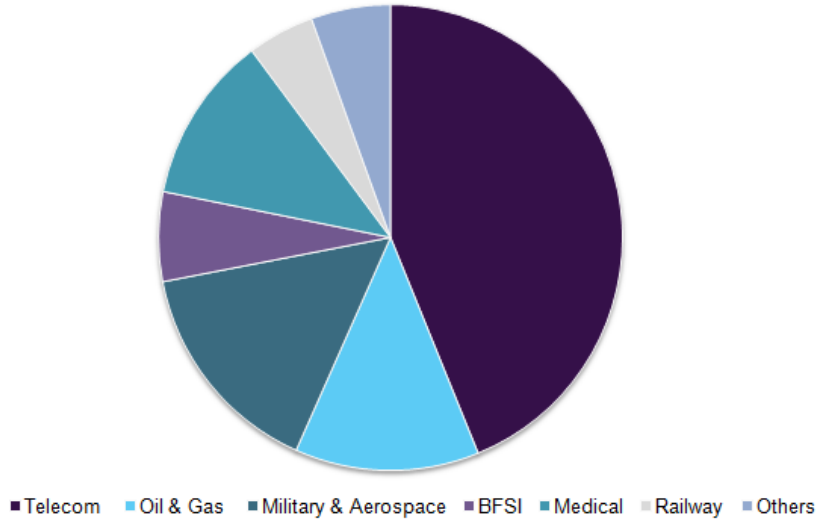

Figure 12 a damaged Connector with a 1.25 mm ferrule that has been over chamfered. The connector must be replaced.
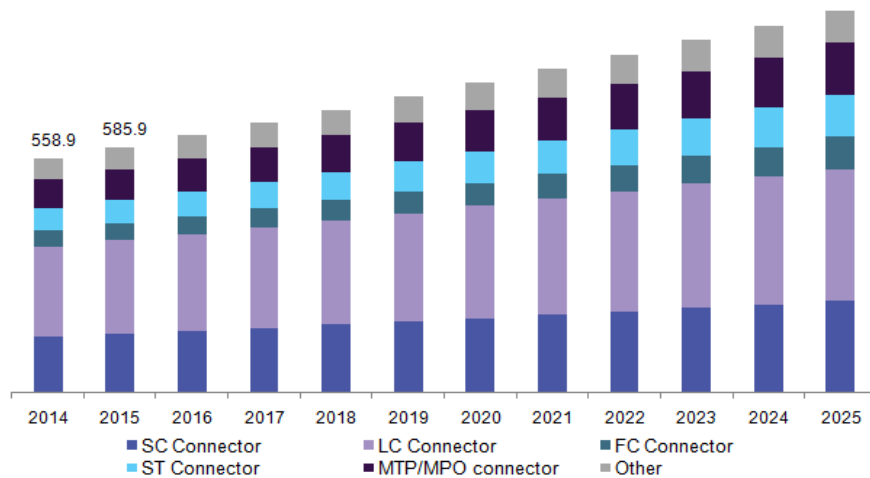
Appendix B

Market Trends
(courtesy Joe Salemi of FiberQA LLC)

Fiber Optic Connector Market expected to reach $5.9B by 2025 CAGR 7.1%
(Grand View Research)

Fiber Optic Market by Application, 2016

■ Telecom ■ Oil & Gas ■ Military & Aerospace ■ BFSI ■ Medical ■ Railway ■ Others

U.S. fiber optic connector market by product, 2014 - 2025, (USD Million)

558.9   585.9

2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

■ SC Connector   ■ LC Connector   ■ FC Connector
■ ST Connector   ■ MTP/MPO connector   ■ Other

References

(1) *IEC Standards*
https://global.ihs.com/doc_detail.cfm?document_name=IEC%2061300%2D3%2D35&item_s_key=00533436

(2) *Photonics Spectra*
https://www.photonics.com/Article.aspx?AID=19082&PID=5&VID=18&IID=106

(3) *"Future Trends in Fiber Optics Communication" by Francis Idachaba, Dike U. Ike, and Orovwode Hope)*
From: Proceedings of the World Congress on Engineering 2014 Vol I, WCE 2014, July 2 - 4, 2014, London, U.K.