Factors Influencing the Optical Performances of Fiber Optic Connectors

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Abstract
Optical connectors are used to connect optical devices to other optical devices or systems. The presence of these optical connectors makes it possible to switch conveniently from one device or system to another. However, each connection introduces a certain amount of insertion and return loss that can impact performance. Such losses are particularly critical at high-speed transmission. Many applications can only tolerate less than 0.1dB loss for a connection. This paper will examine the challenges that manufacturers and users face as they manufacture and/or use fiber optic connectors. This paper will also discuss the factors that influence the optical performance (insertion loss, return loss, etc.) of fiber optic connectors. The losses due to process problem, contamination, and the type of adapters used for connection will be considered.

Introduction

Optical connectors exist everywhere in the world of fiber optics and are needed at different levels: component level, module level and system level. At the component level, optical connectors are used on lasers, receivers/transmitters/transceivers, and couplers, etc. At the module and system levels optical connectors are also needed. Erbium Doped Fiber Amplifiers (EDFAs), Multiplexers (MUXs), Demultiplexers (DEMUXs), Fiber Channels, Optical Systems, etc all use connectors.

Fiber coupling can be accomplished by fusion splicing. Fusion splicing creates permanent fiber coupling with low insertion loss, high strength and smaller size. However, for temporary connections optical connectors are used to produce quick connections and disconnections without the need of splicers. This helps to save considerable connection and test time.

One disadvantage of using connectors is that optical performance may be compromised due to the introduction of unwanted and uncontrollable factors, such as contaminations, scratches, etc. This paper is not intended to give absolute numbers for losses associated with each factor. Our goal is to provide readers with some ideas of the factors that affect the optical performance of the connectors and some relative losses associated with each factor.

Optical Connector- An Overview of Its Structure

Most connectors are designed to produce a butt joint in which the fiber ends are placed as close together as possible. Butt designs include the straight-sleeve, bi-conical and overlap connectors. Butt connectors consist of a ferrule for each fiber and a precision alignment sleeve into which the ferrules fit.[1] The straight-sleeve connector is illustrated in Figure 1. In straight sleeve design, axial and angular alignment are obtained from the smooth fit of the ferrules into the sleeve. The end separation is determined by the length of the ferrule beyond a gap alignment lip and by the length of the sleeve.

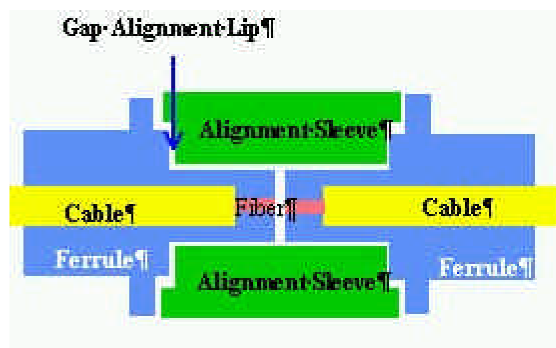

Figure 1 - Straight Sleeve Connector Design

An alternative to the butt configuration is the lensed connector. A lensed connector uses lens to collimate the expanding beam radiating from the transmitting fiber. The lensed configuration is shown in Figure 2. In ordinary connection, fibers are brought in close contact with each other end-to-end. After repeated uses, the end portions of the fibers are damaged or coated with dust, causing an increase in connection loss. The presence of the lens reduces damage and contamination of the end of the fiber. However, lensed connectors are not commonly used due to its complicated structure and difficulty in assembly.

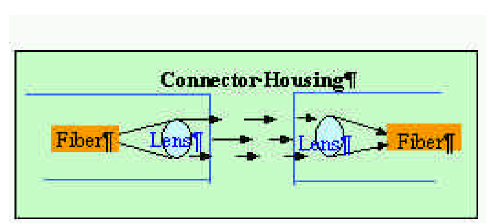

Figure 2 - Lensed Connector Configuration

Contamination

Contamination is the most common cause for degradation in the performance of optical connectors. The core of a single-mode fiber is typically 8 to 9 um and 50 or 62.5 um for multimode fibers. The cladding is 125um. Light travels through the core, and the cladding area helps to bounce the light back to the core. (Human hair is one hundred and twenty-five microns.) So, a couple microns of contaminant can easily reduce the core opening and prevent light transmission particularly in the case of single mode fiber.

Sources of Contamination

Contaminants on the connector end face can come from many different sources. The dust in the air or oil from the human hands can be trapped on the connector end face. The materials from the polishing films can also be left on the connector. Contamination can also be caused by contact with the dust cap. In addition, it can come from the connector adapter or connector housing. No matter how a connector is contaminated, contamination on the optical connector blocks the light and reduces the optical performance of the connector.

Some dirt on the connector end face was detected on an optical microscope at 200X and 400X magnification. Elemental analysis of the contaminants showed presence of Cl, Na, K, and Ca (Figure 3). These are generally found in human oils, dirt, lotions, etc. To prevent this kind of contamination, it is recommended that assembly and test of the connectors be carried out in a clean, controlled environment. The detection of Ni, Cr, Al, and Fe, etc suggests that these particles can come from the connector's adapter or other analytical equipment (see Figure 4 and 5). In addition, some other studies show that cellulose, silicone and mold release agents can be other sources of contamination.[2]

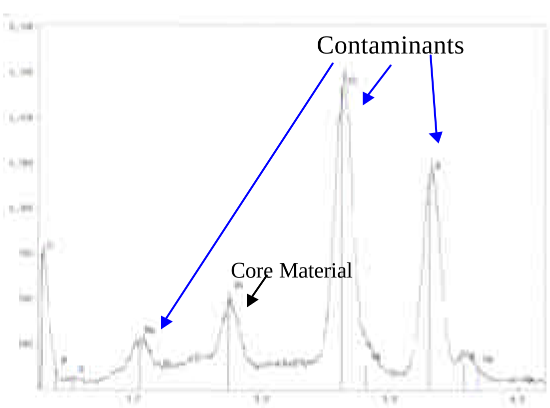

Figure 3 - EDX Spectrum of a Contaminated Connector Showing "Human" Contamination

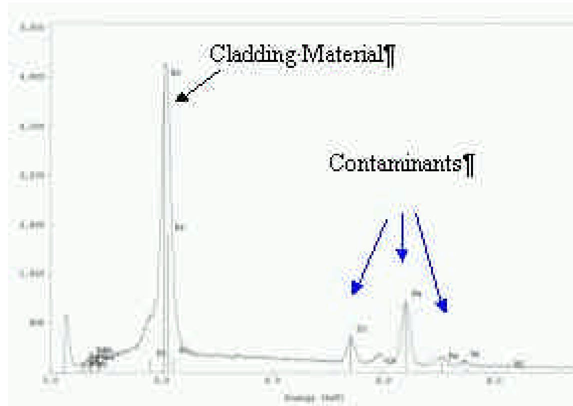

Figure 4 - EDX Spectrum of Optical Connector's Contaminants Showing Contaminants (Cr, Fe, Ni) from Connector Adapter

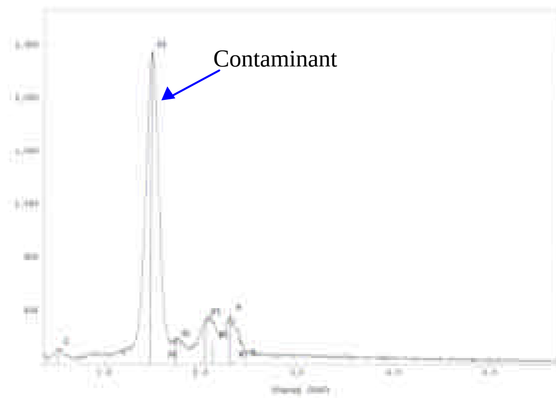

Figure 5 - EDX Spectrum showing that Al is a Source of Contaminations

Performance Degradation Due to Contamination

Figure 6 shows the end face of a stripped optical fiber (the core and cladding) inside the ferrule of a connector. Contaminants can be trapped on any of these three basic areas. Our study shows that particles trapped in the cladding and ferrule areas have little effect on the insertion loss of the fiber optic connector. A loss of about 0.04 dB was seen due to $1000 um^2$ of contaminants on the cladding and ferrule area (see Figure 7).

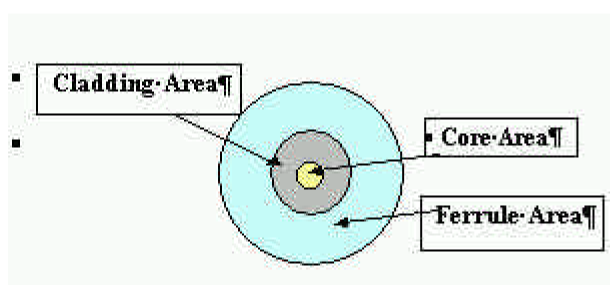

Figure 6 - Contamination Area Classifications

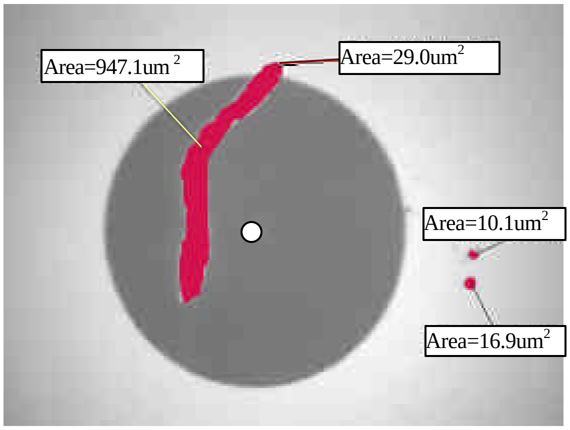

Figure 7 - Contaminations on Cladding-A loss of about 0.04 dB was seen (total contamination area is about 1003.8 um^2)

There is a significant increase in the insertion loss when contaminants get closer to the core (but not on the core yet). A total contamination area of 1120um^2 adds an insertion loss of about 0.5dB (Figure 8). Contamination on the core is very critical and will degrade the optical performance of the connector considerably. A 44um^2 contamination on the core and cladding that blocks about 80% of the core results in an insertion loss of about 1.6dB (Figure 9). It is also expected that a thicker contaminant results in a higher insertion loss. (See Table 1.)

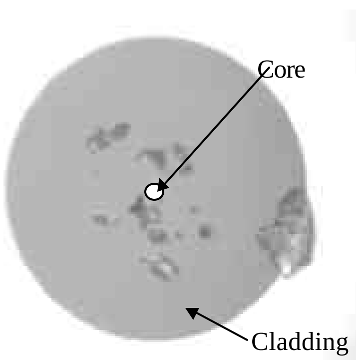

Figure 8 - Contaminants on Cladding and Close to Core Total Contamination Area is about 1120 um^2

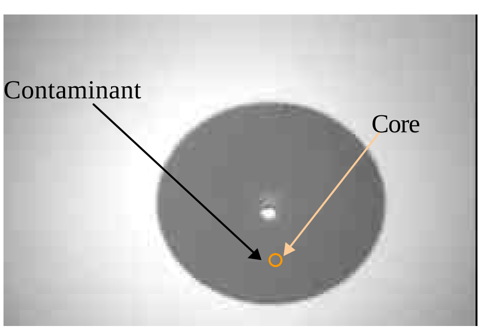

Figure 9 - Contaminant on Core and Cladding Total Contamination Area is about 44um^2

Table 1 - Relationship Between Contamination Size, Location and its Relative Light Loss in dB

Contamination Size [um^2]	**Contamination Locations**	**Delta insertion loss (äIL) [dB] (IL w contamination – IL w/o contamination)**
1004 um^2	Cladding and Ferrule	0.04 dB
1120 um^2	Cladding (close to core) and Ferrule	0.5dB
44 s um^2	Core and Cladding	1.6 dB

Roughness of Connector End Face

Smoothness of the end face on the optical connector can affect its optical performance. The following sections will discuss how scratches influence the performance of optical connector. Scratches can be generated during polishing, cleaning or mating and un-mating of the connectors.

Effects on Return and Insertion Loss

Figure 10 shows images of five different levels of scratches. Table 2 shows that a few light scratches through the cladding and even through the core of the optical fiber have very little effect on the insertion loss of the connector. Few light scratches on the cladding of the optical fiber contribute about a 0.01dB increase in its insertion loss at 1550nm (Figure 10-a, 10b). A light scratch through the core of the connector makes no difference in the insertion loss of the connector at 1550nm, and increases the insertion loss by 0.01dB at 1310nm (Figure 10-b, 10-c). Insertion loss of the connector is significantly increased when there are a lot of scratches on the connector's surface. In this case, an insertion loss of more than 0.2dB was recorded.

The experiment shows that few light scratches on the connector do not significantly affect its insertion loss. However, it shows that scratches play an important role on the return loss of optical connector. Just a few scratches can easily contribute 1-5dB return loss. Approximately 23dB of return loss is seen at medium amount of scratches while there is only 0.02 dB change in insertion loss (Figure 10-a, 10-d). Scratches greatly affect return loss of the connector. It affects insertion loss only when numerous scratches are present on the connector end face.

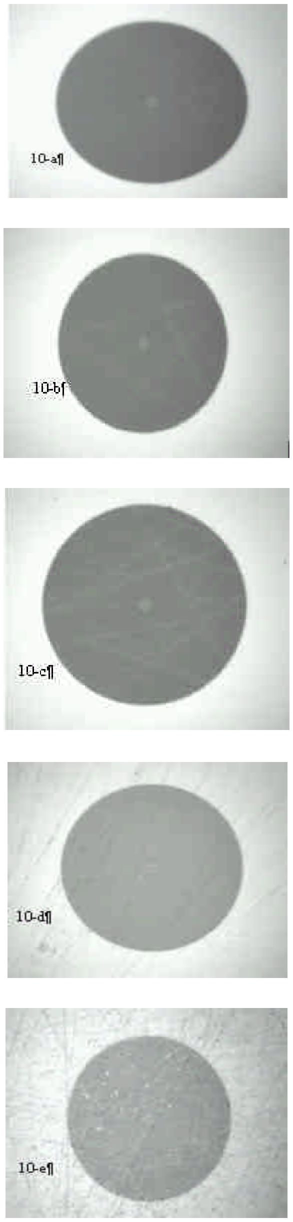

Figure 10 - Scratches on Optical Connector10-a:No scratch; 10-b:Light Scratches; 10-c:Light Scratches through Core; 10-d:Medium Amount of Scratches; 10-e:A lot of Scratches on Connector Endface

Table 2 - The Effects of the Number of Scratches on Performance

Conditions	IL (1550 nm)-dB	RL (1550 nm)-dB	IL (1310 nm)-dB	RL (1310nm)-dB
Good (10-a)	-0.04	-56.5	-0.03	-54.9
Light, Few scratches (10-b)	-0.05	-55.5	-0.03	-54.0
Light scratches through core (10-c)	-0.05	-51.2	-0.04	-49.2
Medium scratches (10-d)	-0.06	-33.3	-0.04	-31.1
Heavy scratches (10-e)	-0.28	-26	-0.29	-24.8

Depth of Scratches

A second experiment was performed to study how the depth of scratches affects the performance of Optical Connector. The results are summarized in Table 3, and its connector end face images are shown in Figure 11. The results confirm the observations of the previous experiment. In addition, it shows that the depth of the scratches affects the insertion loss much more than return loss of the optical connector. With a similar number of scratches (Figure11-b, 11-c), there is about 0.02-0.03 dB of insertion loss if the scratches are shallow. Approximately 0.17dB of insertion loss is introduced when the scratches go deeper into the connector end face. There are about 3 dB differences in the return loss between light and deep scratches. With deep scratches (11-c) and numerous scratches (11-d) the insertion loss increases slightly 0.03-0.04dB, but in the case of heavy scratches, the return loss of its connector increases significantly with a difference of 16dB return loss in the case of heavy scratches on the connector surface.

Table 3 - The Effects of Depth of Scratches on Optical Connector Performance

Conditions	IL (1550nm) dB	RL (1550nm) dB	IL (1310nm) dB	RL (1310nm) dB
Good (11-a)	-0.08	-56.2	-0.08	-54.6
Light/Med scratches (11-b)	-0.10	-46.2	-0.11	-44.8
Deep light/med scratches (11-c)	-0.25	-43.4	-0.25	-41.6
Heavy scratches (11-d)	-0.28	-27.2	-0.29	-25.6

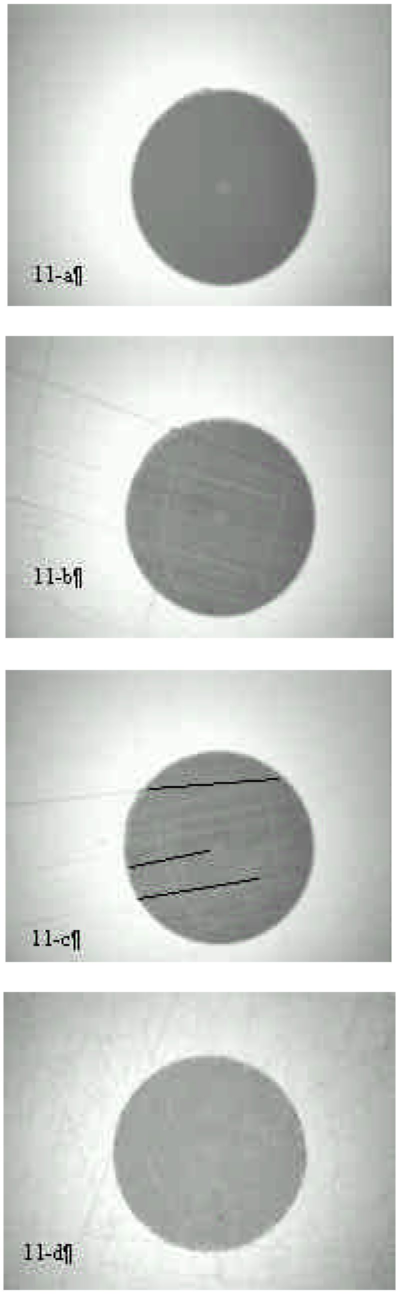

Figure 11 - Scratches on Optical Connector 11-a: No scratch; 11-b: Light Scratches; 11-c: Deep Scratches; 11-d: Heavy Scratches

Connector Adapter Types

The insertion and return loss of FC and SC connectors were measured using different connector adapters.

In general, an adapter connecting the same types of optical connectors generates lower insertion loss than one connecting different types of connectors. In other words, an adapter connecting an FC connector to another FC connector or an SC connector to another SC connector results in lower connection loss. When the connectors at two opposite ends of the adapter are not the same, that is in the case SC to FC or FC to SC adapters, an increase of 0.01-0.02 dB insertion loss is usually seen. However, few exceptions are seen. One case shows that the connection using different types of adapter can cause almost 1dB higher insertion loss. Few cases of SC connectors show using different types of adapter give lower insertion loss than using same type connector adapter (Figure 12). SC connectors' return losses show that same SC/SC adapter gives a better performance. However, using different type connector adapter results in a lower return losses for FC connectors (Figure 13). This may be due to the difference in the connector design.

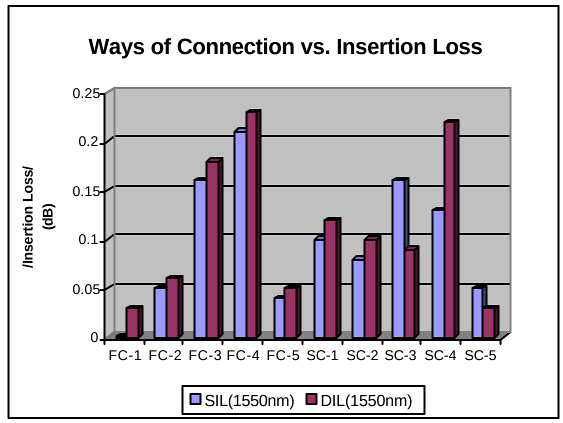

Figure 12 - Insertion Loss Measurements Using Different Connection Means. SIL = Insertion Loss Using Same Type Connector Adapter. DIL=Insertion Loss Using Different Type Connector Adapter

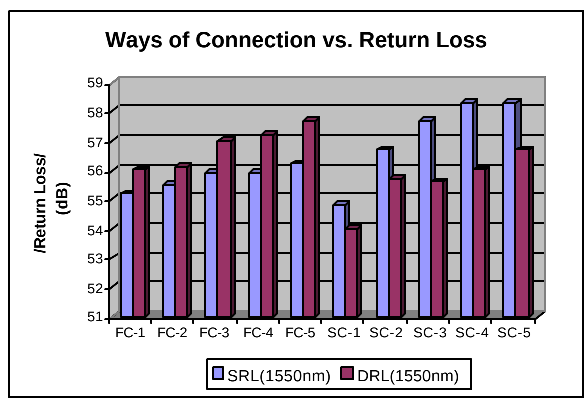

Figure 13 - Return Loss Measurements Using Different Connection Means. SRL = Return Loss Using Same Type Connector Adapter. DRL = Return Loss Using Different Type Connector Adapter

Optical Performances of Fiber Optic Connector At Different Wavelengths

The insertion and return losses of SC fiber optic connectors are measured at two different wavelengths, 1310nm and 1550nm. The insertion and return loss measurements are shown in Figure 14 and

Figure 15, respectively. In general, it shows little wavelength dependence effects on the insertion loss of an optical connector. The insertion losses measured at 1550nm are identical to that measured at 1310nm in many cases. Some cases show that the measurements at 1310nm tend to give higher insertion loss than at 1550nm. For the return loss (reflectance) of fiber optic connector, the reflectance measured at 1550nm is typically 1dB higher than that measured at 1310nm. This may be due to the characteristics of fiber materials in which fiber attenuation is lower at 1550nm than at 1310nm.

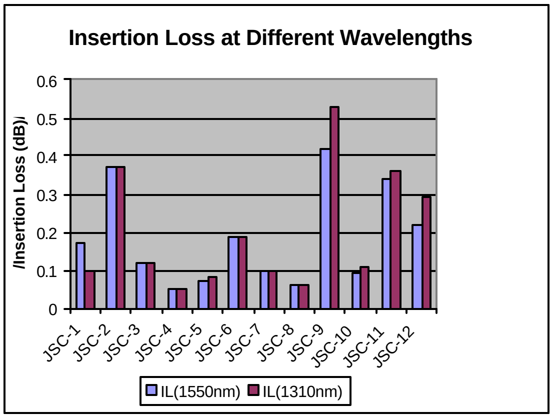

Figure 14 - Insertion Losses of Optical Connectors at Different Wavelengths

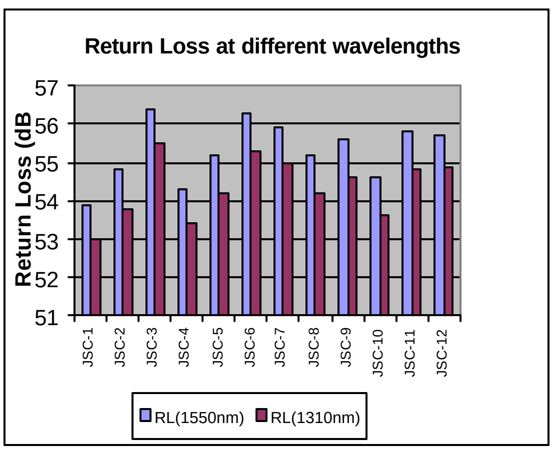

Figure 15 - Return Loss of SC Fiber Optic Connectors at Different Wavelengths

Conclusions

Many factors contribute to high signal losses of optical connectors.

- The presence of contaminants is the most common factor that degrades the optical performance of the connector. Contamination can be eliminated by proper cleaning of the optical connectors before connection.

- Scratches at the connector end face have a big effect on the return loss and have little effect on the insertion loss if those scratches are light and not deep into the fiber.
- Connecting and measuring a connector through a same connector adapter will generally give better insertion losses. Connecting and measuring a connector through a same connector adapter may give better or worse return losses depending on the type and design of the connector.
- The insertion loss of an optical connector shows very little wavelength dependency. However, it is clear that measurements made at 1550nm gave better return loss than at 1310nm. This difference is about 1-2dB.

Acknowledgements

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2. Tatiana Berdinskikh and Jason Bragg, *Factors Influencing Contamination of Fiber Optic Connectors and Optical Modules*, IPC International Conference on Opto-Electronics, May 3-4,2001, p35-69.