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Applications
Engineering Note

Multimode Splice Loss

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Introduction

Splicing is required to create a continuous path for light transmission from one fiber to another. Two different methods exist for splicing fibers:

- Fusion splicing – melting fiber ends together
- Mechanical splicing – holding fiber ends together using a mechanical coupling device

Typical splice loss values (the measure of loss in optical power across the splice point) are usually lower for fusion splices (typically less than 0.1 dB) than for mechanical splices (around 0.2 dB). The primary contributors to measured splice loss are fiber material and design factors that prevent an optimal coupling of the light pulses from one fiber end to another. Fiber misalignment and fiber geometry mismatch (e.g., core size, core-to-clad concentricity, core and cladding non-circularity, numerical aperture, etc.) can result in real power loss across a splice joint. However, differences in the backscattering coefficients between two fibers can also show up as an exaggerated loss or even a power gain across the splice, but are not indicative of a real change in optical power.

Fiber misalignment is a byproduct of the splicing process and can occur with any splice. Even when splicing identical fibers together, if they are not perfectly aligned, optical power will be lost and attenuation across the splice will exist. Likewise, mismatches between fiber geometry and intrinsic fiber parameters (e.g., numerical aperture) can result in the loss of optical pulse power and must be taken into account when conducting splicing operations. Therefore, fibers can be divided into two groups:

1. Similar Fibers - fibers having the same core diameter and similar intrinsic properties.

2. Dissimilar Fibers - fibers having different core diameters (e.g. 50 mm, 62.5 mm, etc.) and/or intrinsic properties that result in additional measured power loss across a splice joint

These categories of fibers are addressed in greater detail below.

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Splicing Similar Fibers

When splicing similar fibers, the fiber core alignment has the highest influence on the quality of the splice. Even highly sophisticated fusion splicers cannot fully compensate for these misalignments. See Figure 1 below for a comparison of fiber core misalignment (a.k.a. offset) vs. power loss.

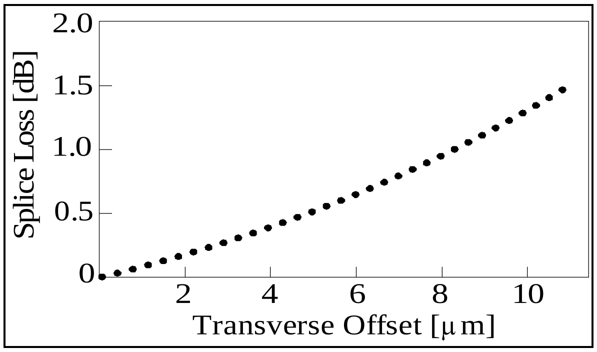

Figure 1: Transverse Offset

Fiber alignment is even more critical for mechanical splices, where no active optical alignment systems exist. In these cases, transverse as well as longitudinal fiber offset (the space between fiber ends) must be considered. Additionally, cleave quality (angle and roughness of end faces) will also influence the splice performance.

Splicing Dissimilar Fibers

To connect two fibers together in which there are differences in the geometrical and intrinsic properties, a closer look must be taken at the main fiber characteristics which result in a higher indicated splice loss. Core diameter and numerical aperture contribute the most to real splice loss, while differences in the scattering coefficients can contribute to a higher measured power loss, or even a power gain.

Core Diameter/ Numerical Aperture

There are two types of multimode fibers predominant in current optical fiber systems. They are 50/125 micron and 62.5/125 micron. The 50 and 62.5 indicate the nominal diameter of the fiber cores and the 125 represents the nominal diameter of the cladding, all in units of microns (µm). However, core diameter differences can also exist within each multimode fiber type due to variations in the manufacturing processes. Since differences in fiber core size between fibers of the same fiber type (i.e., 50/125 µm or 62.5/125 µm) are typically very small, they contribute little to actual splice loss. However, splicing dissimilar fiber types together (i.e., 50/125 µm to 62.5/125 µm) can result in significant optical power loss. Two possible scenarios are addressed below.

1. Splicing a small core fiber (50/125 µm) to a large core fiber (62.5/125 µm).

2. Splicing a large core fiber (62.5/125 µm) to a small core fiber (50/125 µm).

The first case indicates an "underfilled" situation. Since the receiving fiber is larger than the transmitting fiber, all the core power is transferred from the small core to the large core. See Figure 2 below.

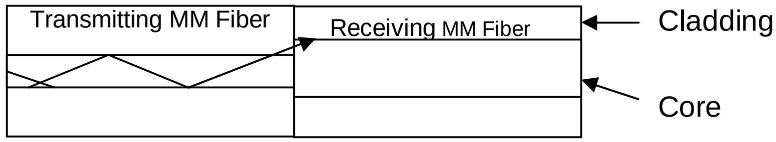

Figure 2: Underfilled Situation

The second case represents an "overfilled" situation, in which only a certain amount of power can be transmitted from the large core fiber to the small core fiber due to the loss of some of the light that is transmitted into the cladding. See Figure 3 below.

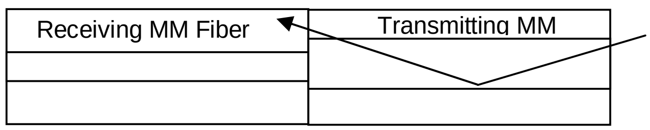

Figure 3: Overfilled Situation

The loss due to this overfilled situation can be calculated as follows:

$$\text{Loss}_{\text{overfilled}} \approx \text{Loss}_{d} + \text{Loss}_{NA}$$

$$\text{Loss}_{d} \approx -10\log\left(\frac{d_{re}}{d_{tr}}\right)^{2} \quad [\text{dB}] \quad d_{re} < d_{tr}$$

$$\text{Loss}_{NA} \approx -10\log\left(\frac{NA_{re}}{NA_{tr}}\right)^{2} \quad [\text{dB}] \quad NA_{re} < NA_{tr}$$

Where: d_{re} = core diameter of the receiving fiber
d_{tr} = core diameter of the transmitting fiber
Na_{re} = numerical aperture of the receiving fiber
Na_{tr} = numerical aperture of the transmitting fiber

These equations show that the higher the mismatch of numerical aperture and core diameter, the higher the occurring attenuation penalty. It must be emphasized that this loss is truly a directional loss, appearing only for the overfilled situation.

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Example:

The following example shows what attenuation penalty must be considered when splicing a large core fiber (62.5 mm) to a small core fiber (50 mm), when the large core fiber is transmitting, using nominal values for NA:

$$Loss_d \approx -10\log\left(\frac{d_{re}}{d_{tr}}\right)^2 \approx -10\log\left(\frac{50}{62.5}\right)^2 \approx 1.94 \text{ dB}$$

$$Loss_{NA} \approx -10\log\left(\frac{NA_{re}}{NA_{tr}}\right)^2 \approx -10\log\left(\frac{0.2}{0.275}\right)^2 \approx 2.76 \text{ dB}$$

$$Loss_{overfilled} \approx Loss_d + Loss_{NA} = 4.7\text{dB}$$

Therefore, an additional theoretical splice loss of 4.7 dB must be accounted for when splicing 62.5 micron fiber to 50 micron fiber. This additional loss originates only due to the mismatch of the fibers and does not account for the quality of the splice.

Scattering Coefficient

Scattering is the loss of optical energy due to the molecular structure of the fiber and the embedded impurities. The parameter has relatively little to do with actual power loss at a splice joint; however, it can cause problems by creating erroneous attenuation readings on Optical Time Domain Reflectometer (OTDR) test equipment. OTDR measurements are based on the assumption that the amount of backscattered light is proportional to the intensity of the light traveling down the fiber. If this value changes between the two fibers on either side of a splice, it results in erroneous readings on the OTDR, because OTDRs cannot compensate for this intrinsic difference between the two fibers. The result is an exaggerated power loss, or in some instances a displayed gain in optical pulse power. See Corning Optical Communications' Applications Note 41, "Multimode Gainers," for additional information.

Summary

When splicing similar fibers, typical splice loss values (less than 0.1dB fusion or 0.2 dB mechanical) are expected. However, when splicing dissimilar fibers, additional factors must be taken into account when testing the quality of the splice. Two general scenarios are:

1. Small core (transmit) to large core (receive)

- Typical splice loss values are expected

2. Large core to small core (large core fiber is transmitting)

- Additional loss due to power transmitted into cladding of receiving fiber

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