Evaluation of the Link Loss Budget of the POF

Kazuya Takayama
Nitto Denko Corporation
Objectives

・To estimate the loss of graded index plastic optical fiber (GI-POF) connection at mating sleeve
  (Coupling loss between light source/detector and GI-POF is not included.)

・Giving the idea of loss budget to be assigned for GI-POF link
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Sample Information

• GI-POF patch cord (commercially available GI-POF and parts)
  Core/Clad: 50μm/490μm
  Length: 3m x 10 pcs. (#01~#10), 40m x 1 pc.
  Termination: LC connector with metal ferrule
  Attenuation: ~0.1dB/m
Near-Field/Far-Field Pattern Meas.

Apparatus

NFP: LEPAS-12 (Hamamatsu Photonics K.K.)
FFP: M-Scope type F (Synergy Optosystems Co., Ltd.)
Light Source: FOLS-01, 856nm LED (Craft Center SAWAKI Inc.)
quartz 200μm core, NA0.48, L~1m, FC connector output
Launch Condition: Fiber Butt Coupling

Samples

POF sample, 3m x 10pcs. (#01~#10), 40m x 1pc.

Measurement Result

<table>
<thead>
<tr>
<th>POF length</th>
<th>Beam Diameter (3σ)</th>
<th>Beam Divergence (3σ)</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 m</td>
<td>52.2μm (0.8μm)</td>
<td>20.2° (0.2°)</td>
<td>0.175</td>
</tr>
<tr>
<td>40 m</td>
<td>45.1μm (1.7μm)</td>
<td>18.8° (0.2°)</td>
<td>0.163</td>
</tr>
</tbody>
</table>

- Higher-order mode is attenuated after 40m of propagation.

Fig. 1 Typical NFP image and NFP profile of sample POF
Insertion Loss Measurement

Measurement Configuration:

**Insertion Loss**

- **Light Source**
  - LED (850nm)

- **Mode Scrambler**
  - Photom 100G
  - (Graytechnos Co., Ltd.)

- **Optical Power Meter**
  - Photom Model 208
  - (Graytechnos Co., Ltd.)

- **Photo Detector**

- **Mating Sleeve**

- **Fiber Under Test** (measured for both directions)

**Fig. 2** Schematic image of insertion loss measurement setup

**POF core displacement**

- POF core displacement from the center of ferrule OD was measured.
- Both of the fiber end were measured.
- Labeled as 1A, 1B, ⋯, 10B
Insertion Loss and Core Displacement

Measurement Results:

Fig. 3  Lateral displacement of POF core from the center of ferrule

- Relatively large displacement of POF core was observed.
- Positive correlation was confirmed between the core displacement and the insertion loss.

Fig. 4  Relationship between insertion loss and POF core displacement
Displacement at the Mating Point

For each of mating combination, we can calculate the lateral core displacement by using the data on the previous page.

Fig. 5  Schematic image of calculation method for POF core displacement
Connection Loss due to Lateral Displacement of Core

In order to understand and estimate the coupling loss for POF connection, with displacement, different core diameter, NA, etc., theoretical approach is taken for the next step.

※Additional 0.5dB was subtracted to calculate the loss increased by mating. (Attenuation 0.3dB, Fresnel Loss 0.2dB)
Calculation Method\textsuperscript{[1],[2]}

The near-field power distribution as a function of core radius, $r$, can be described by

$$I(r) = A \left( 1 - \left( \frac{r}{R} \right)^g \right)$$ \hfill (1)

Total power, $P_T$, equals

$$P_T \approx 2 \times A \int_0^\pi \int_0^R \left( 1 - \left( \frac{r}{R} \right)^g \right) r dr d\theta$$ \hfill (2)

When there is the core displacement in lateral direction, the area of core overlap needs to be integrated. In addition, local NA is different for both fiber ends, such as transmitting fiber and receiving fiber. This efficiency needs to be considered as well.
Calculation Method\textsuperscript{[1],[2]}

Then, transmission coefficient at a radial distance $r$ from the core axis is introduced.

$$P_T \cong 2 \times A \int \int t(r_1) \left( 1 - \left( \frac{r_1}{R} \right)^g \right) r_1 dr_1 d\theta$$  \hspace{1cm} (3)

$$t(r_1) = \begin{cases} 1 + Qp_0 - p_0^Q & \text{for } Q < 1 \\ 1. & \text{for } Q \geq 1 \end{cases}$$  \hspace{1cm} (4)

$$Q = \frac{(NA_2)^2}{(NA_1)^2} = \frac{\Delta_2 (1 - r_2^g)}{\Delta_1 (1 - r_1^g)}$$  \hspace{1cm} (5)

Integration region will vary depends on the core displacement value.

$P_T$ is the total power transmitted through the fiber, $A$ is the cross-sectional area of the fiber, $R$ is the radius of the core, $g$ is a parameter, $Q$ is a parameter related to the core displacement, $p_0$ is a parameter to define the beam width of the Gaussian distribution at the calculation point.

$p_0$ is a parameter to define the beam width of the Gaussian distribution at the calculation point.
Validation of the calculation method

Method:

- 850nm VCSEL
- Mode-scrambler
- OM2 Fiber (bare fiber)
- Optical Power Meter

Receiving fiber was manually shifted and receiving power was recorded.

Result:

Measurement and calculation showed good agreement.

$p_0=0.1\sim0.4$ can be used to estimate the loss due to the core displacement.

Fig. 6 Simulated loss and measured coupling loss
Comparison of Simulation against Meas.

- Calculated loss due to core displacement was overlapped to Figure 6.
- Measurement data doesn’t show good agreement with calculation.
- The trend matches with the calculation.
- There seems to be some offset, such as unidentified loss about 0.6dB or 3-4μm of further displacement.
- Further experiment by using bare fiber is necessary to validate this approach.

Fig. 7  The comparison of calculated loss and measurement
10GbE Link Test

Test Configuration:

![Diagram of test configuration](image)

**Test Results:**

<table>
<thead>
<tr>
<th>Total Link Length (m)</th>
<th>Connections</th>
<th>Fiber Order</th>
<th>BER</th>
<th>Insertion Loss (I.L.) (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2.57</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1-3</td>
<td>0</td>
<td>4.38</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>1-3-4</td>
<td>0</td>
<td>6.00</td>
</tr>
<tr>
<td>12</td>
<td>3</td>
<td>1-3-4-7</td>
<td>0</td>
<td>8.37</td>
</tr>
<tr>
<td>15</td>
<td>4</td>
<td>1-3-4-7-6</td>
<td>0</td>
<td>10.80</td>
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<tr>
<td>18</td>
<td>5</td>
<td>1-3-4-7-6-8</td>
<td>0</td>
<td>13.60</td>
</tr>
<tr>
<td>21</td>
<td>6</td>
<td>1-3-4-7-6-8-10</td>
<td>1.24E-06</td>
<td>16.70</td>
</tr>
<tr>
<td>24</td>
<td>7</td>
<td>1-3-4-7-6-8-10-2</td>
<td>4.78E-04</td>
<td>18.00</td>
</tr>
<tr>
<td>27</td>
<td>8</td>
<td>1-3-4-7-6-8-10-2-5</td>
<td>1.28E-02</td>
<td>20.50</td>
</tr>
<tr>
<td>30</td>
<td>9</td>
<td>1-3-4-7-6-8-10-2-5-9 -</td>
<td>21.80</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6.8</td>
</tr>
</tbody>
</table>

- Error-free communication was confirmed up to 15m (4 connections).
- However, it may depend on the FOT or other causes, such as mechanical tolerance of mating sleeve, etc.

10GbE LANPHY test: “0” means error free up to $10^{-11}$. 
Summary

Connection loss calculation method for fiber splicing was applied to mechanical mating sleeve.

There is a deviation between the calculated loss due to core displacement and measurement.

Dimensional tolerance of mating sleeve, ferrule, needs to be considered to conclude this experiment.

Error-free communication was confirmed up to 15m (4 connections) for 10GbE LAN/PHY test.

Thank you for your attention!
References
