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Evaluation of the Link Loss Budget of the POF

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Objectives

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- 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

Contents

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1. Sample Information
2. Near-Field / Far-Field Pattern Measurement
3. Insertion Loss Measurement
4. Connection Loss due to Lateral Displacement of Fibers
5. Calculation Method of Connection Loss and its Validation
6. Comparison of Simulation against Measurement
7. 10GbE Link Test (Eye pattern vs Link#)
8. Summary

Sample Information

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・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.

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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

POF length	Beam Diameter (3σ)	Beam Divergence (3σ)	NA
3 m	52.2μm (0.8μm)	20.2° (0.2°)	0.175
40 m	45.1μm (1.7μm)	18.8° (0.2°)	0.163

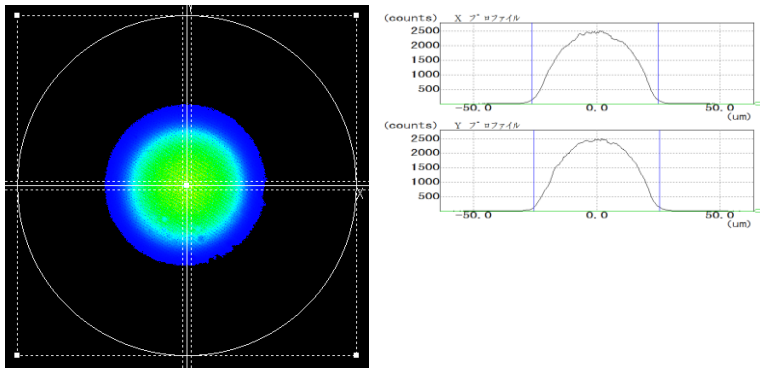


Fig. 1 Typical NFP image and NFP profile of sample POF

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

Insertion Loss Measurement

Measurement Configuration:

Insertion Loss

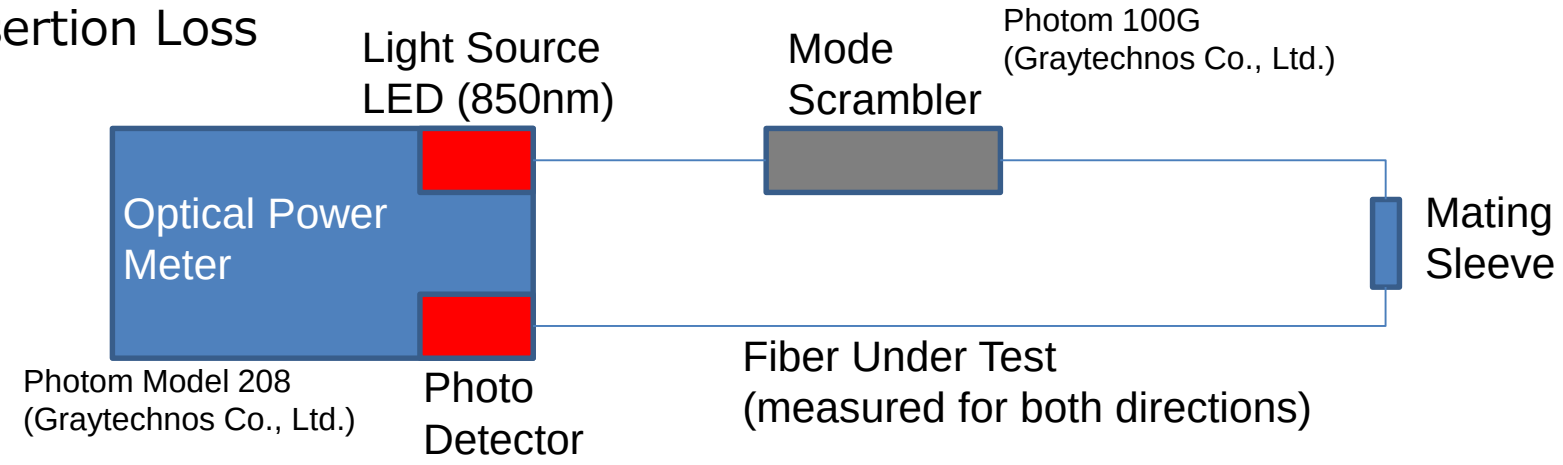
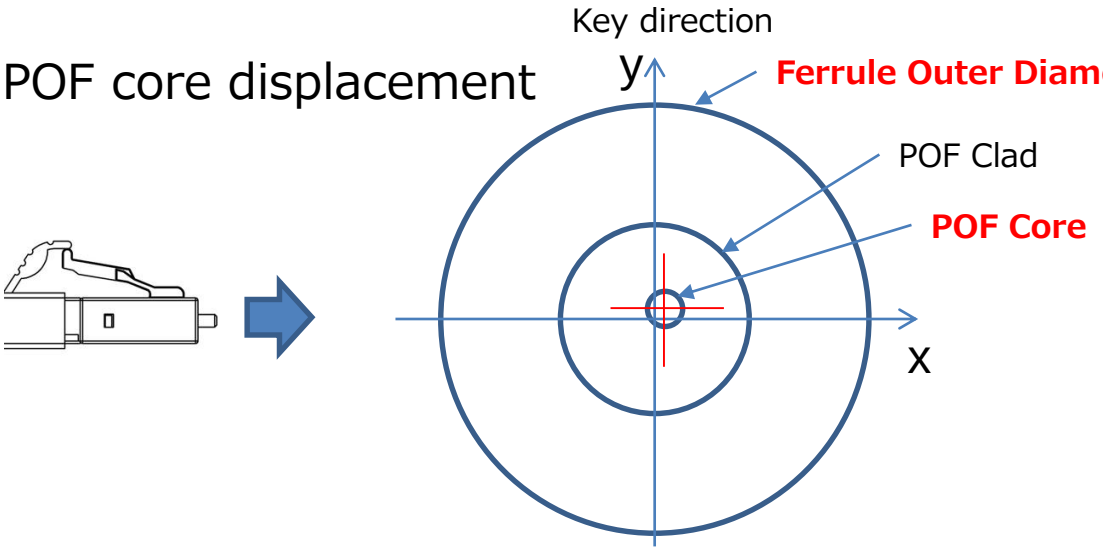


Fig. 2 Schematic image of insertion loss measurement setup

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

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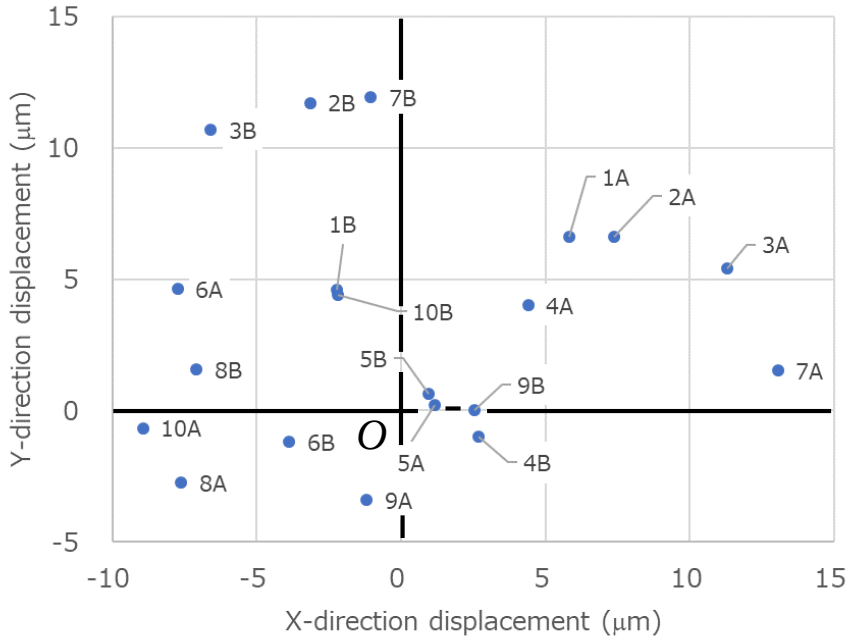
Measurement Results:



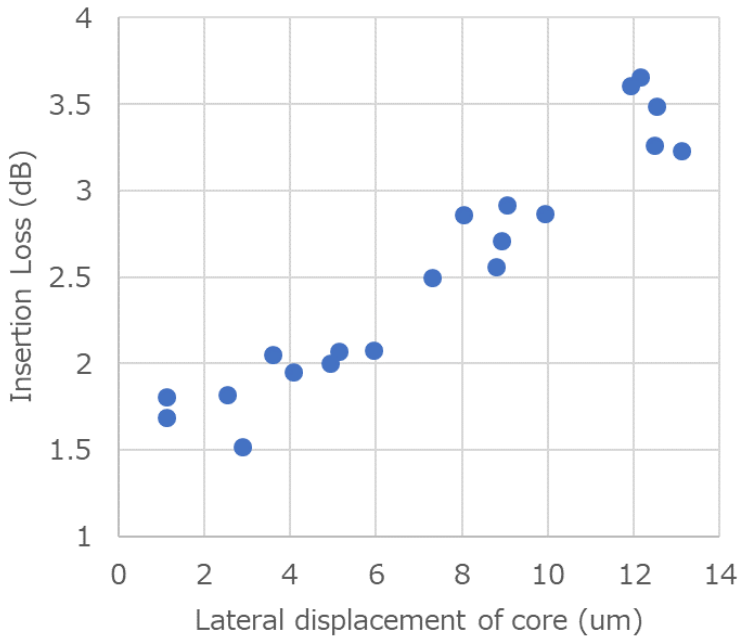


Fig. 3 Lateral displacement of POF core from the center of ferrule

Fig. 4 Relationship between insertion loss and POF core displacement

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

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.

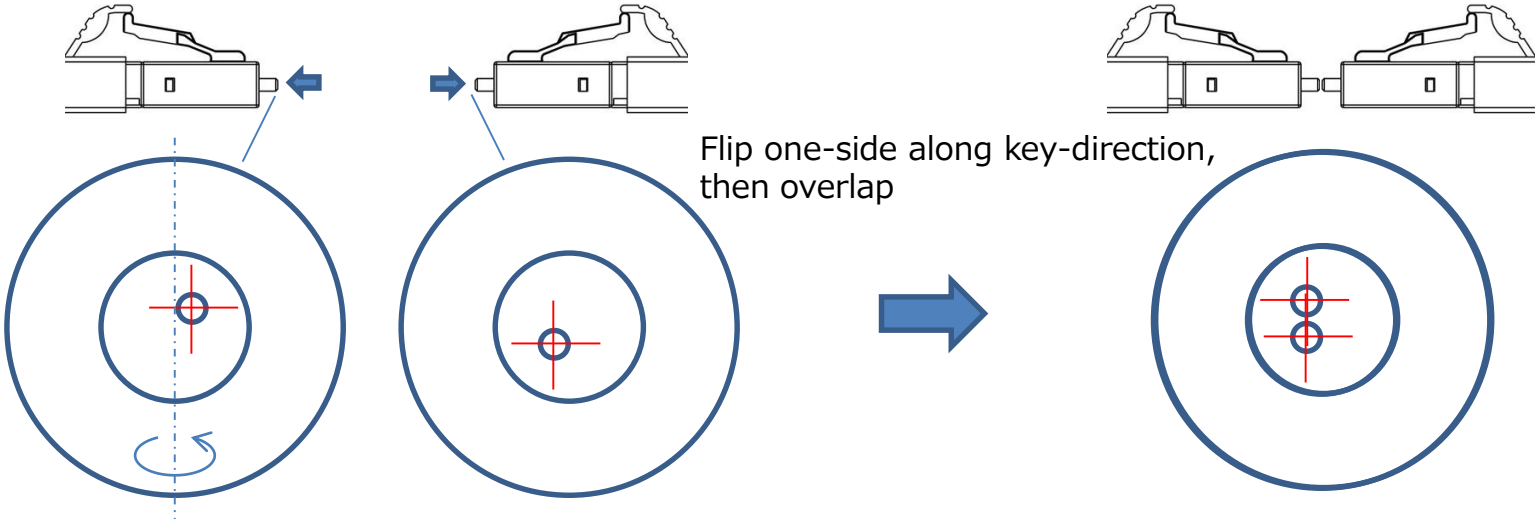
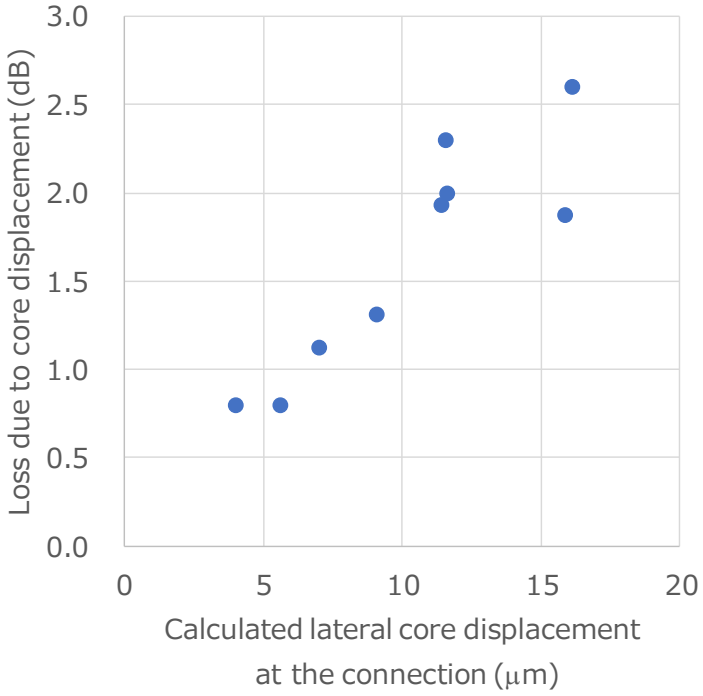


Fig. 5 Schematic image of calculation method for POF core displacement

Connection Loss due to Lateral Displacement of Core

Total Link Length (m)	Connections	Fiber Order	Insertion Loss(I.L.) (dB)	Δ(I.L.)-0.5 (dB) ※	Mating Combination	Calculated Core Displacement (μm)
3	0	1	2.57			
6	1	1-3	4.38	1.31	1B-3A	9.09
9	2	1-3-4	6.00	1.12	3B-4A	7.03
12	3	1-3-4-7	8.37	1.87	4B-7A	15.91
15	4	1-3-4-7-6	10.80	1.93	7B-6A	11.44
18	5	1-3-4-7-6-8	13.60	2.30	6B-8A	11.59
21	6	1-3-4-7-6-8-10	16.70	2.60	8B-10A	16.16
24	7	1-3-4-7-6-8-10-2	18.00	0.80	10B-2A	5.65
27	8	1-3-4-7-6-8-10-2-5	20.50	2.00	2B-5A	11.66
30	9	1-3-4-7-6-8-10-2-5-9	21.80	0.80	5B-9A	4.04

※Additional 0.5dB was subtracted to calculate the loss increased by mating.
(Attenuation 0.3dB,
Fresnel Loss 0.2dB)



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.

Calculation Method[1],[2]

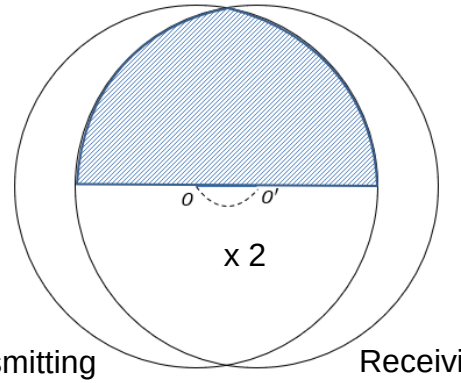
The near-field power distribution as a function of core radius, r, can be described by

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

Total power, P_T, equals

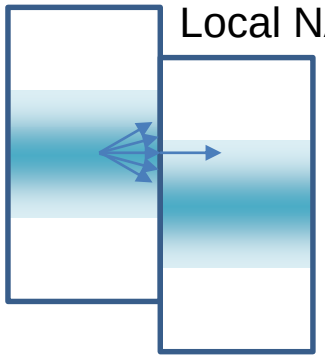
$$P_T \cong 2 \times A \int_0^{\pi} \int_0^{R} \left(1 - \left(\frac{r}{R}\right)^{g}\right) r\,dr\,d\theta \quad (2)$$

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.



Transmitting Fiber

Receiving Fiber



Calculation Method[1],[2]

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

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

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

$$\mathrm{Q} = \frac{(NA_2)^2}{(NA_1)^2} = \frac{\Delta_2\left(1-r_2^g\right)}{\Delta_1\left(1-r_1^g\right)} \tag{5}$$

1:Transmitting Fiber
2:Receiving Fiber

Integration region will vary depends on the core displacement value.

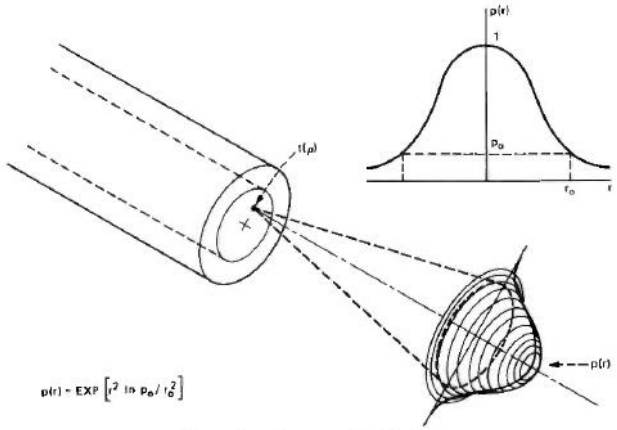
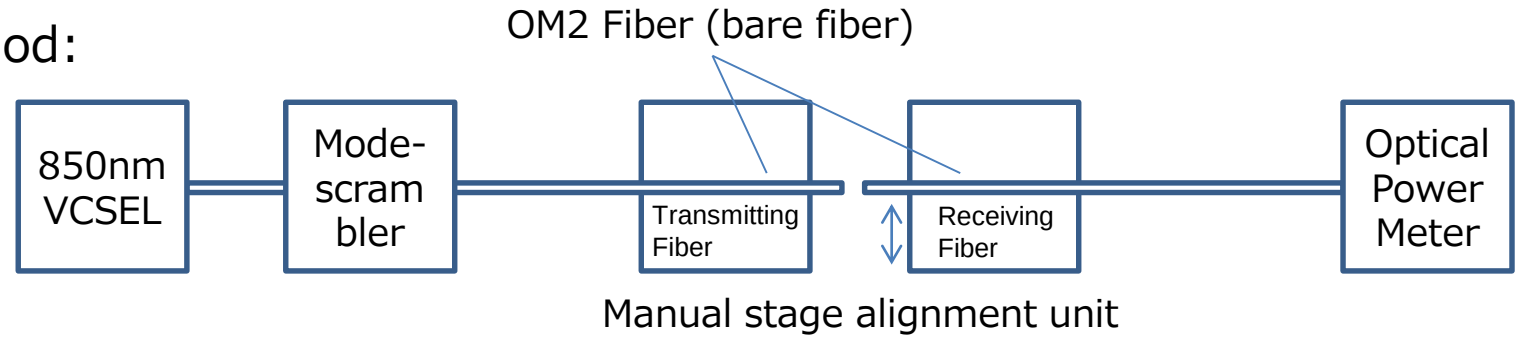


Fig. 1—Gaussian power distribution.

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

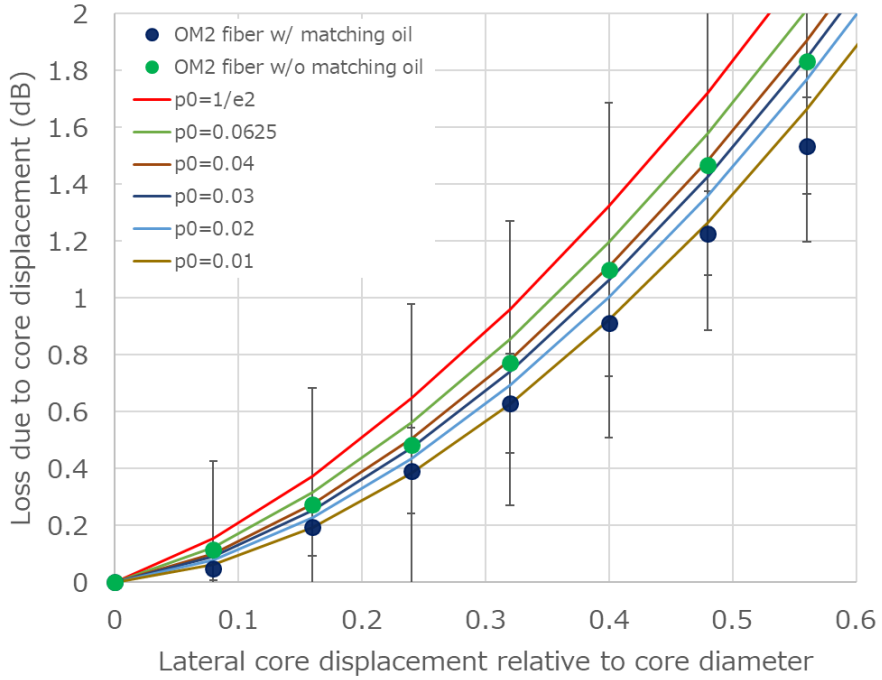
Validation of the calculation method

Method:



Receiving fiber was manually shifted and receiving power was recorded.

Result:



Measurement and calculation showed good agreement.

p_0=0.1~0.4 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.

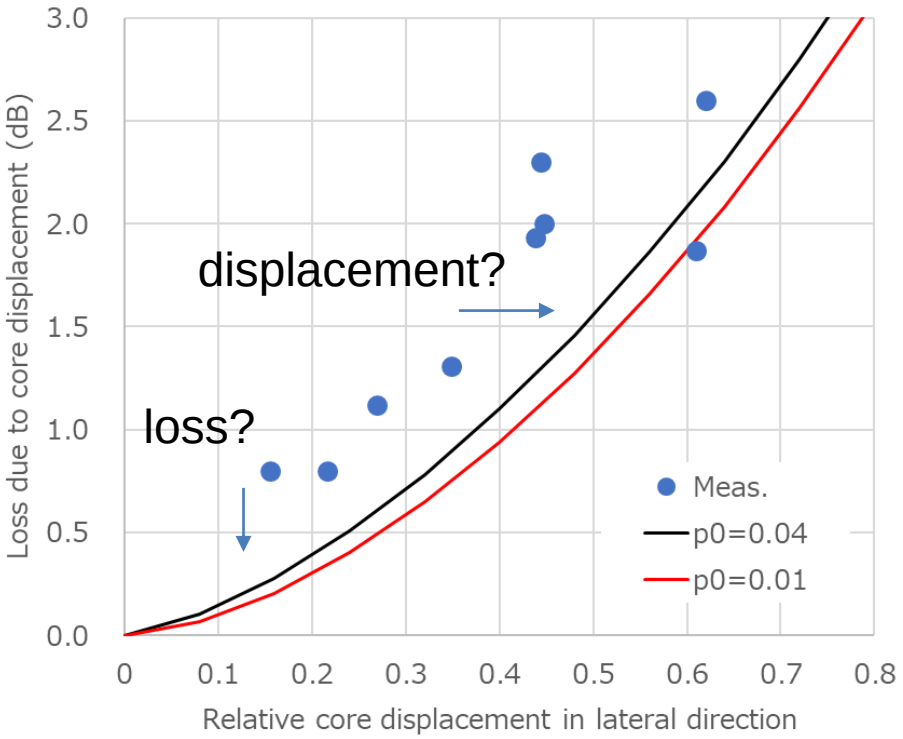


Fig. 7 The comparison of calculated loss and measurement

- Calculated loss due to core displacement was overlapped to Figure6.
- 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.

10GbE Link Test

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Test Configuration:

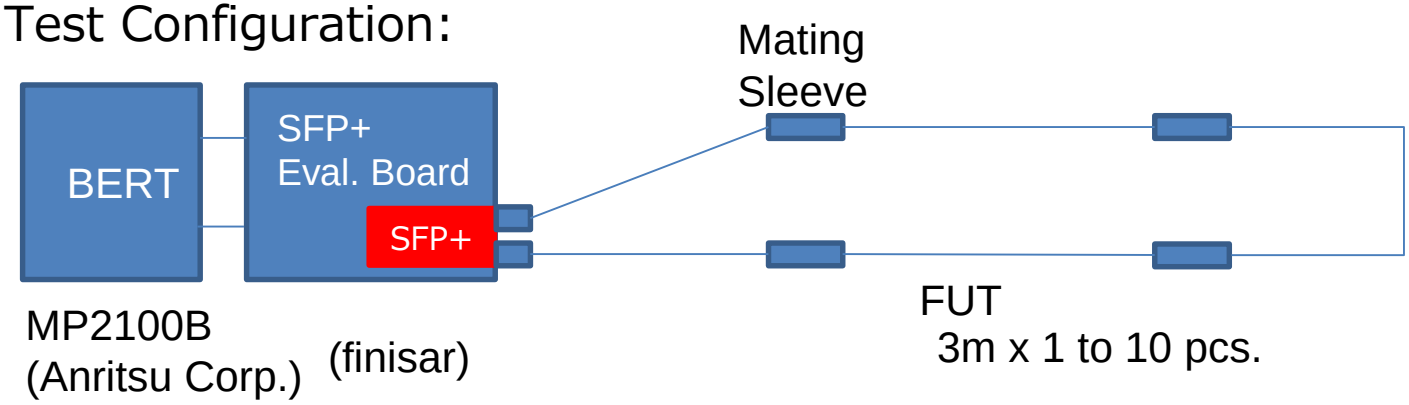
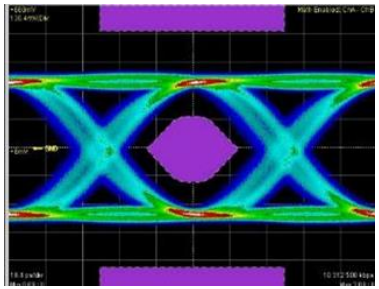


Fig. 8 Schematic image of insertion loss measurement setup

Test Results:

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



10GbE LAN/PHY test:
"0" means
error free up to 10^{-11}.

- 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.

Summary

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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

[1] C. M. Miller, “Transmission vs Transverse Offset for Parabolic-Profile Fiber Splices with Unequal Core Diameters,” B.S.T.J., 55, No. 7, pp. 917-927 (1976).

[2] S. C. Mettler, “A General Characterization of Splice Loss for Multimode Optical Fibers,” B.S.T.J., 58, No. 10, pp. 2163-2182 (1979).