# Analyzing return loss deterioration of optical fiber joints with various air-filled gaps over wide wavelength range

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**Abstract:** We experimentally investigated the return loss of optical fiber joints with various air-filled gaps. We discovered that the return loss might deteriorate to 8.6 dB for one connector and 5.9 dB for four-connected connectors at worst.

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## 1. Introduction

A large number of optical fiber connectors and mechanical splices have been used in such optical subscriber networks as fiber-to-the-home (FTTH) systems [1]. Physical contact (PC)-type connectors are mostly used in these fiber joints for intra-office use and on premises where frequent reconnections are required. In contrast, connectors and mechanical splices with refractive index matching material are mostly used in outside facilities, where frequent reconnections are unnecessary but where low cost joints are needed. Recently, field installable connectors using both PC connectors and refractive index matching material have been developed and used in FTTH systems [2]. The optical performance of these fiber joints has already been reported [3]-[5]; however, some points remain unclear. Unexpected faults after installing these fiber joints might have a detrimental effect on performance. For instance, when an air gap occurs unexpectedly at the contact point with PC-type connectors or connectors using index matching material, the return loss becomes noticeably worse. It is important to understand the worst possible optical performance of these fiber joints to make it possible to guarantee the overall performance of a system.

We have investigated the optical performance of fiber joints with various gaps. In OFC/NFOEC2009, we reported that the insertion loss might deteriorate more than 30 dB at worst for fiber joints with a mixture of refractive index matching material and air-filled gaps [6]. We here experimentally determine the return loss characteristics of fiber joints with air-filled gaps over a wide wavelength range. The worst return loss which we indicate is much smaller than the Fresnel reflection 14.6 dB at a fiber end in air and might result in the performance deterioration of a system. These results support the practical construction and operation of optical network systems.

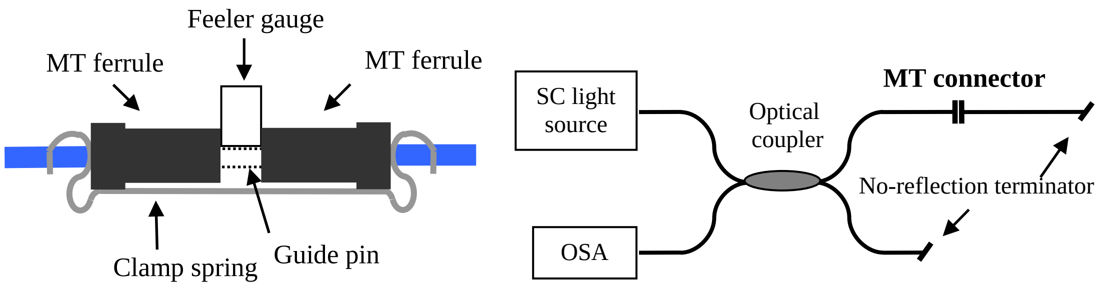
## 2. Optical fiber joints with air-filled gap

We focus our investigation on the characteristics of optical fiber joints caused by the gap between the fiber ends. Misalignments of the offset and tilt between the fibers and the mode field mismatch are not considered. An analysis of optical performance caused by a gap between fiber ends is based on a multiply reflection to behave like a Fabry-Perot interferometer [5]. On the basis of the analysis, the Fresnel reflection $R_0$ at a fiber end in air and the reflection $R$ of optical fiber joints with an air-filled gap are defined by the following equations.

$$R_0 = \left( \frac{n_1 - n}{n_1 + n} \right)^2 \tag{1}$$

$$R = \frac{4R_0 \sin^2 (2\pi n S / \lambda)}{(1 - R_0)^2 + 4R_0 \sin^2 (2\pi n S / \lambda)} \tag{2}$$

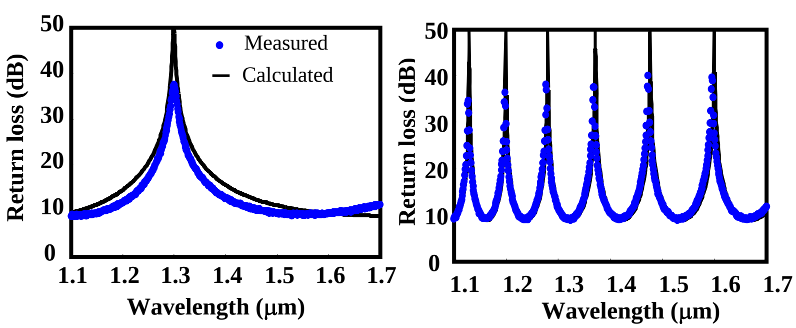
The return losses in dB are derived by taking the log of the reflection function. Here $n_1$ and $n$ are refractive indices of the fiber core and air, respectively. According to Eq. (2), the return loss depends on wavelength $\lambda$ and gap size $S$. We experimentally investigated wavelength dependence of the return loss of fiber joints with various air-filled gaps.




(a) (b)

Fig. 1 (a) Experiment sample using MT connector and feeler gauge and (b) experimental setup.

A schematic view of the experimental sample and setup using a mechanically transferable (MT)-connector is shown in Fig. 1. MT-type connectors, which in the experiment were assembled with 1.3-μm zero-dispersion fibers, are generally used in outside plants for connecting multifiber array ribbons and have a small gap between two fiber ends that is filled with refractive index matching material to reduce Fresnel reflection. A feeler gauge (thickness gauge tape) is set and fixed between the two MT ferrules of the connector with a certain gap size using a clamp spring. By changing the thickness of the feeler gauge, various sizes of gaps can be obtained. An air-filled gap is obtained without using refractive index matching material. The return loss of the MT connector with an air-filled gap was measured over a wide wavelength range using a supercontinuum (SC) light source, an optical spectral analyzer (OSA), and an optical coupler. The SC light source can output more than +20 dBm/nm higher power than the conventional halogen lamp light source. Therefore, wide return loss values of the connectors can be obtained for the first time over a wide wavelength range.




(a) **(b)**

Fig. 2 Return loss results using MT connector
(a) without feeler gauge and (b) with 10-μmfeeler gauge.

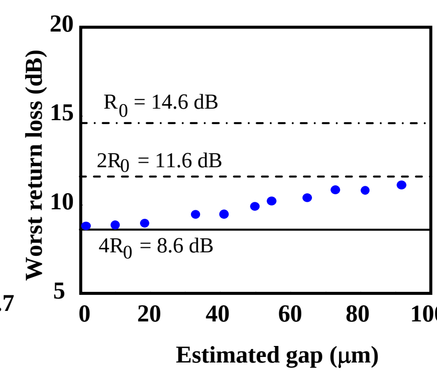



Fig. 3 Relationship between estimated gap size and worst return loss.

## 3. Results and discussion

The results of conventional MT connectors without a feeler gauge and with a 10-μm feeler gauge are shown in Figs. 2 (a) and (b), respectively. The circles and solid lines represent measured results and the calculations based on Eq. (2), respectively. Here, the refractive indices $n_1$ and $n$ are 1.454 and 1.0, and the gap size $S$ for calculations is 1.3 μm in (a) and 9.6 μm in (b). These two sets of measured results are in good agreement with the calculations. The return losses for the air gaps varied greatly and periodically and resulted in a worst value of about 9 dB. As the gap is larger, the wavelength period is smaller. These results indicate that although gap size is not equal to the thickness of the feeler gauge, the experiment using the feeler gauge is useful for the analysis of fiber joints with various air-filled gaps. Moreover, the gap size between fiber ends can be estimated based on measured returns losses and calculations using Eq. (2). We used various feeler gauges and measured the return losses. Figure 3 shows the relationship between the worst return loss over a wide wavelength range of 1.1-1.7 μm and the estimated gap size based on the measurements and calculations. When the gap is small, the worst return loss is about 8.6 dB, which is four times the Fresnel reflection $R_0$ at the fiber end in air. As the gap size increases, the worst return loss increases. When the gap size is over 90 μm, the worst return loss changes to about 11.6 dB, which is twice $R_0$. This is because when the gap is larger between fiber ends, the loss occurred and the interference caused by multiply reflection becomes weak. Therefore, the worst return loss increases. Consequently, for one connector with an air-filled gap, the return loss might deteriorate remarkably when the gap is small, resulting in 8.6 dB in the worst case.

We performed another experiment using multi-connected MT connectors with an air-filled gap. First, we connected two MT connectors with a 10-μm and then a 20-μm feeler gauge using a 6-m fiber patch cord. The return losses over a wide wavelength range were measured. The results are shown in Fig. 4. The return loss from two-connected connectors is equivalent to the summation of each reflection and might deteriorate to 7.1 dB at worst. Next, we connected two, three, and four MT connectors without feeler gauges using 6-m fiber patch cords and measured each respective return loss. The results of the connected MT connectors are shown in Fig. 5. As the connected number increases, the return loss becomes worse. In Fig. 5, the return losses worsen to 8.8, 7.0, 6.4, and 5.9 dB for the one connector and two-, three-, and four-connected samples, respectively, over a wide wavelength range of 1.1-1.7 μm.

Consequently, the return loss of the connectors with an air-filled gap was investigated over a wide wavelength range of 1.1-1.7 μm. The return losses vary depending on wavelength, gap size, and connected connector number. In the worst case, the return loss was about 8.6 dB for one connector with an air-filled gap and 5.9 dB for four-connected connectors with an air-filled gap. These worst return losses are much smaller than the Fresnel reflection 14.6 dB at a fiber end in air and might result in the performance deterioration of a system.

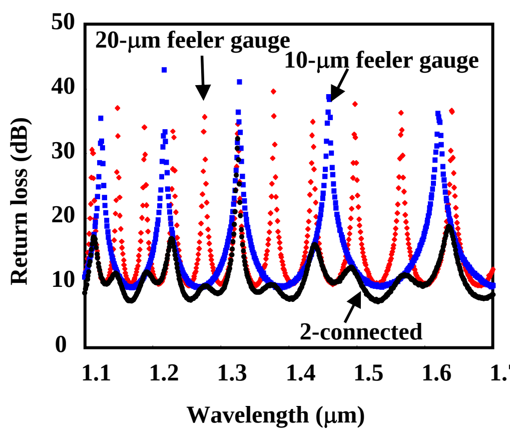



Fig. 4 Return loss results using two connected MT connectors with 10- and 20-μm feeler gauges.

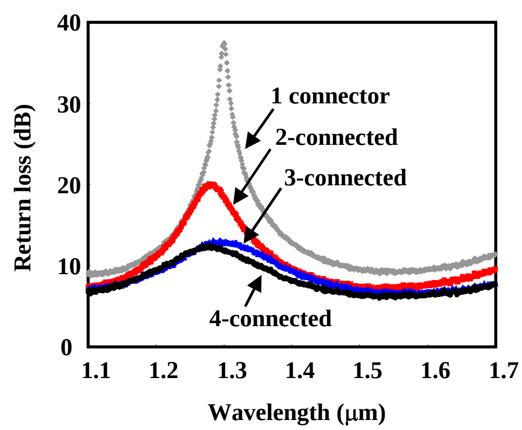



Fig. 5 Return loss results using multi-connected MT connectors without feeler gauge.

## 4. Conclusion

We experimentally investigated the return loss deterioration for fiber joints with an air-filled gap. The experimental results revealed that the return loss of the fiber joints varied widely. At worst, the return loss could deteriorate to 8.6 dB for one connector and 5.9 dB for four-connected connectors. These results can support the construction and operation of optical network systems.

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