The Non-Contact Connector: A New Category of Optical Fiber Connector

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Abstract: We report on a new category of fiber connectors called non-contact connectors. By introducing a gap between anti-reflection coated fiber facets, a connector with outstanding optical performance, reliability and low cost is achieved.
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There are two categories of optical fiber connectors in general today. In the first category are conventional connectors; these are based on physical contact and were developed in the 1980s with an eye toward simplicity and ease of implementation.

If there is a gap between two fiber facets of optical fiber connectors, there are multiple reflections at the facets which interfere coherently and cause insertion loss to vary by as much as 0.6dB, resulting in a potentially bad connection [1]. The simplest way to remove the multiple reflections is to eliminate the gap through tight physical contact. The advantages of this approach included low manufacturing cost and the ability to create connector terminations in the field. Since the performance of the physical contact connector was sufficient for most purposes, it is no surprise that it quickly became the standard for the fiber optics industry and has remained so for the past three decades. However, connectors based on the physical contact mechanism frequently suffer from problems because there can sometimes be an unintended air gap. An air gap can occur due to various means, such as dust and other contaminants, and imperfect match of connector geometry. Finally, repeated physical contact results in surface damage and limited lifetime.

A second category of connector is the expanded beam connector, where a lens is used to collimate an expanded beam. This type of connector is very robust at maintaining tolerable optical connection but suffers from poor optical performance, higher cost and complexity. Insertion loss is typically 0.8 dB and return loss is 34 dB, both very poor values compared to physical contact connectors. This type of connector finds very limited applications in harsh environments.

In this paper, we report a new category of optical fiber connectors called non-contact (NC) optical fiber connectors (patent pending), which is based on a new operating principle of proximity coupling. Figure 1 shows an angled non-contact connector (ANC), which is made by modifying physical contact connectors. For clarity, only the fiber-ferrule assembly is shown. Other necessary parts of a connector including the housing, the spring, the latching mechanism and the strain relief boot are not shown here.

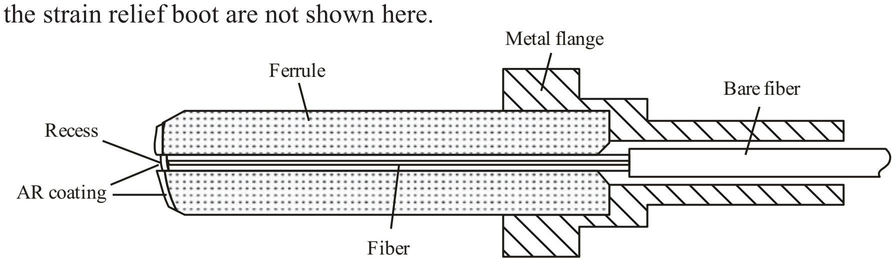

Fig. 1. Schematic cross section of an angled non-contact connector.

In Figure 1 there is a spherical polished end face on the ceramic ferrule. The polished fiber facet is slightly recessed from this polished end face, and an anti-reflection (AR) coating covers the polished end face and the fiber facet. Other than the recessed fiber facet and the AR coating, this connector is identical to conventional connectors and uses the same piece parts and same connector adapters.

Figure 2 shows the details of a pair of such ANC connectors mated together. A precise air gap exists between the two AR coated fiber facets due to the raised ferrule end faces which form a spacer structure. The AR coated ferrule surfaces make contact during operation, but not the fiber facets. Vastly improved mating life results from this non-contact design. The harmful multiple reflections at the fiber facets are reduced by the AR coating to low levels, and the 8° facet angle can reduce the magnitude of the back reflection even further. Commercial AR coatings with 0.2% residual reflectivity can be used.

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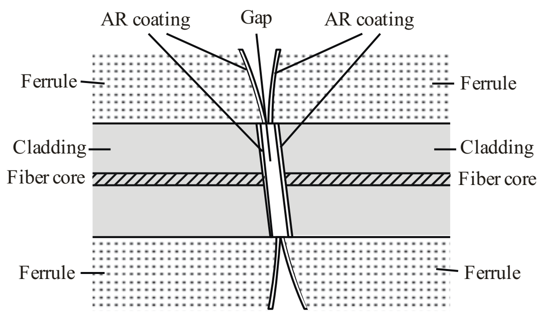

Fig. 2. Detailed view of a pair of ANC connectors

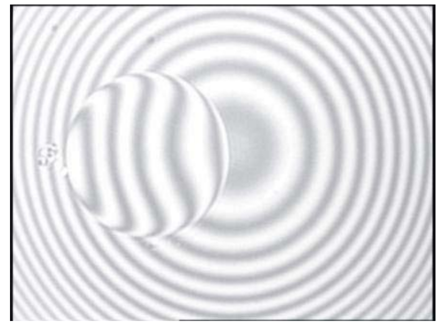

Fig. 3. Interference diagram of the surface of an ANC connector

The fiber recess is typically from 0.3µm to 10µm. Due to the nature of Gaussian optics, light beam can couple from one fiber to another with negligible loss when the gap is very small compared to the Rayleigh range, which is about 93µm for SMF-28 single mode fiber at 1550nm wavelength.

Figure 3 shows the recessed fiber surface of an ANC connector measured using a fiber interferometer. To show continuous surface contours, the surface is tilted at a 6° angle instead of 8°, otherwise only broken contours will appear. The recessed depth is estimated to be 0.4µm. A connector polishing machine is used with a 0.5 micron cerium oxide flocked polishing film, which has many micro brushes. The recess is formed because the abrasive particles embedded in the micro brushes polish the softer glass much faster than the harder zirconia ceramic ferrule. Uniformity of the polish depth is excellent and a scratch-free surface typically results from this final polish step.

Figure 4 shows insertion loss result during random mating of a number of single mode SC/ANC connectors. Insertion loss of NC connector is very low and about the same as an APC connector, which proves that a pair of AR coatings operating at such close distance poses no problem. The insertion loss is dominated by the fiber core positional error of the raw materials used. Other critical parameters in physical contact connectors such as radius of curvature, apex offset, and fiber height have little impact in the case of NC connectors.

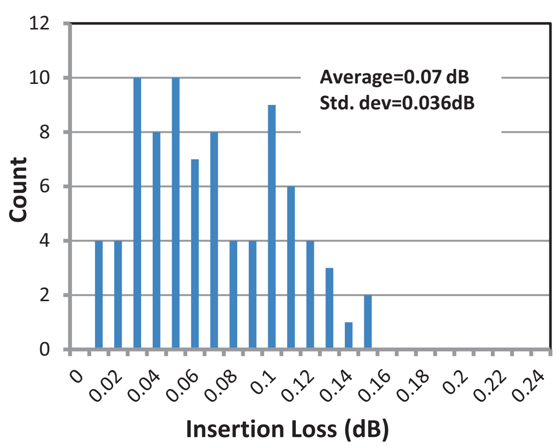

Fig. 4. Insertion loss during random mating

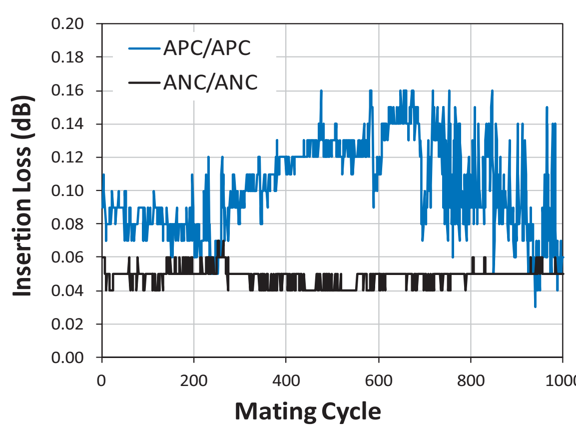

Fig.5. Repeatability of mating of ANC conenctors. Top curve is from a pair of APC connectors for comparison.

NC connector completely solves the intermittent random mating problem of physical contact connectors, because the unintentional air gap which causes trouble for physical contact connectors does not pose a problem for NC connectors. NC connector can guarantee 100% random mating among any compatible connector pair and is therefore a much more reliable optical fiber connector.

Figure 5 shows the repeatability of NC connector during 1000 matings. The variation in the insertion loss is less than 0.01dB. NC connector should prove ideal for lab measurements. To determine the durability of NC connector, we did 10,000 matings for a pair of SC/ANC connectors. Insertion loss remained unchanged from beginning to end of the test at 0.12dB. At the end, AR coating is still intact.

Figure 6 shows the return loss measurement result of various angled connectors using a high resolution OTDR tester. Return loss of an ANC connector is about 10 dB better than an APC connector. This high return loss performance can be an important factor in state of the art fiber optic communication systems, because low reflection noise should allow significantly enhanced system performance with negligible cost increase.

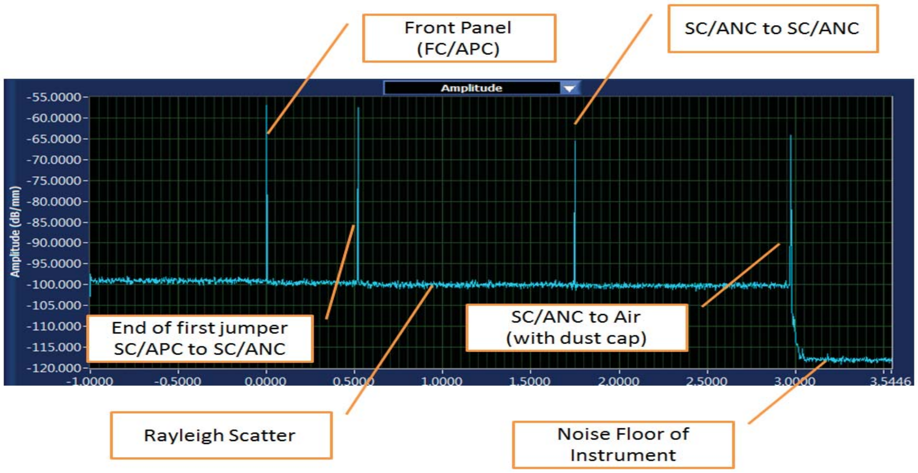

Fig. 6. Optical return loss of ANC connector measured by an OTDR.

NC connectors are compatible with conventional physical contact connectors. Table 1 shows typical performance values for various compatible mating configurations. It can be seen that ANC/ANC configuration offers the best performance in terms of insertion loss and return loss.

Table 1. Typical performance of various connector mating configurations

Connector Mating Type	PC/PC	PC/NC	NC/NC	APC/APC	APC/ANC	ANC/ANC
Insertion Loss	0.1 dB	0.25 dB	0.1 dB	0.1 dB	0.25 dB	0.1 dB
Return Loss	40 dB	14 dB	28 dB	60 dB	60 dB	70 dB
Guaranteed Connection	No	Yes	Yes	No	Yes	Yes

Using NC connectors as test jumpers to test physical contact connectors has emerged as a popular early application, because the non-contact nature of NC connectors greatly reduces fiber surface damage. Customers use LC/NC connectors to test small form factor optical transceivers. Because of the surface normal polish angle, return loss is only 14 dB. Testing transceivers with built-in isolators is preferred. One customer reported a 5-fold reduction in device damage as a result of using NC test jumpers during manufacturing.

AR coating is an additional processing step for NC connectors compared to physical contact connectors. In order to drive down manufacturing cost, a vast quantity of connector ferrule-fiber assemblies must be coated in the same vacuum chamber. Some 20,000 ferrule-fiber assemblies can be coated in the same coating run, and the added cost for each unit is only a few cents. Leaving the heavily reinforced cable outside is paramount, because it can cause outgassing in a vacuum chamber and take up additional space. Preferably, only bare fiber is loaded into the chamber. After AR coating, AR coated NC connector ferrule assemblies can be fusion spliced to any reinforced fiber cable types using the so-called splice-on connector processes. The spliced point is protected using splice protector and is hidden inside the connector body. NC connectors are factory made, but field installable.

Some initial reliability testing and environmental testing of NC connector have been performed.

Conclusion: We have demonstrated a new category of optical fiber connector, the non-contact connector. It offers major improvements compared to conventional physical contact fiber connectors while maintaining low manufacturing cost.

References

[1] Suzuki, N., M. Saruwatari, and M. Okuyama, "Low Insertion- and High Return-Loss Optical Connectors With Spherically Convex-Polished End," Electron Lett. , Vol. 22, 1986, p.110.