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Advanced Components

Application Note

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Key Error and Apex Ofset in APC Connectors

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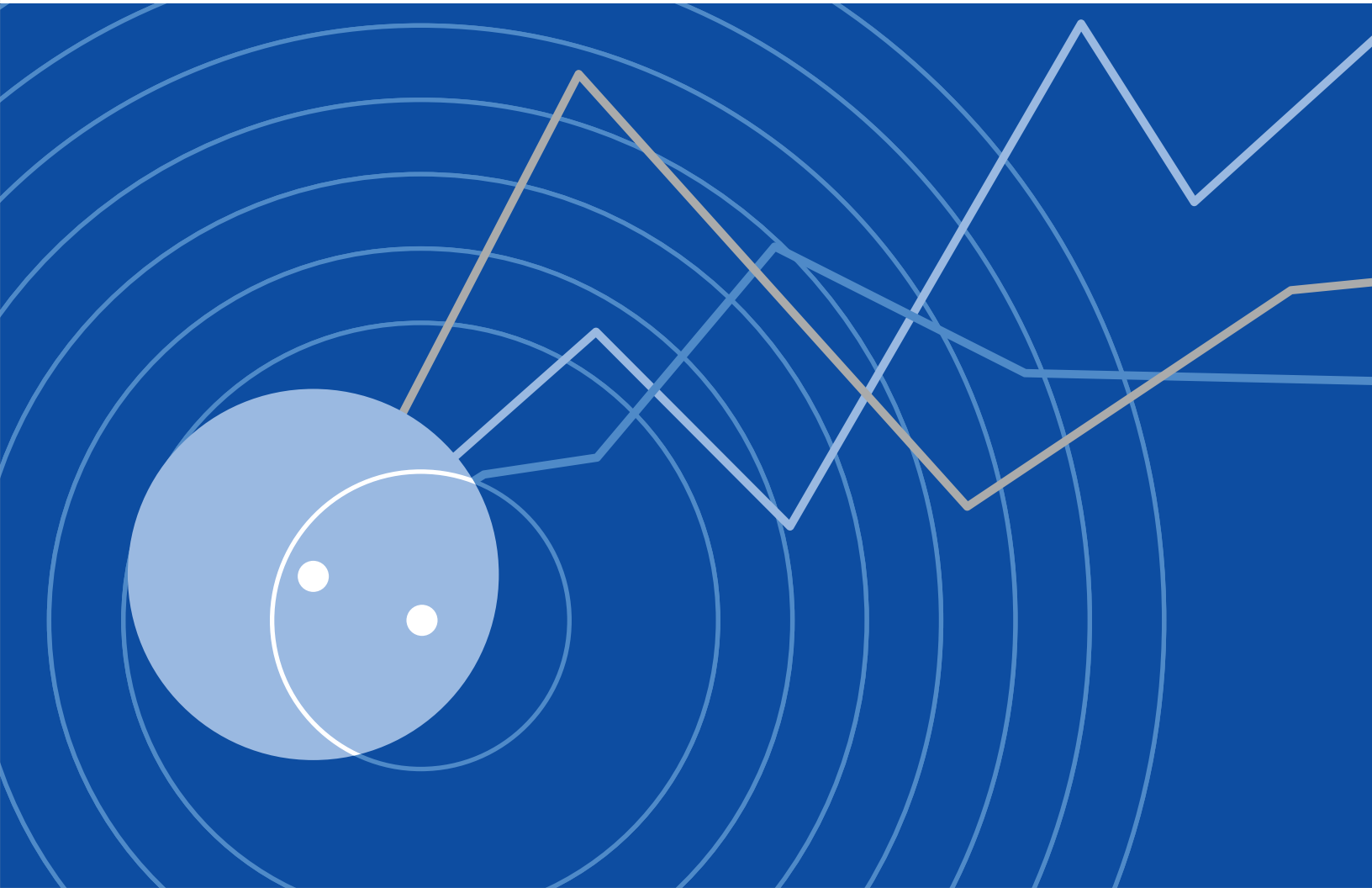

1.0 Introduction

Optical fiber, like a copper cable, is prone to signal reflection known as Return Loss (RL). In a metallic conductor this is caused by a discontinuity (impedance mismatch), while in an optical fiber network the dominant factor for reflection is called Fresnel reflection. Fresnel reflection is caused by light undergoing a change in the index of refraction at the interface between fiber (n = 1.5) and air (n ~ 1).

An air gap at the connection point is a typical cause. Reflected signals can create an undesirable effect for optical fiber systems, causing the laser diode power output to become unstable, resulting in a reduction of output power. They can also disturb the standing optical wave or oscillation in the laser's cavity, increasing noise and generating Bit Error Rates (BER).

Traditionally, Ultra Physical Contact (UPC) connectors with RLs of up to 55 dB have been good enough to reduce the undesired RL. However, the introduction of higher bandwidth networks require even less reflection. This is why the Angled Physical Contact (APC) connectors, with the improvements to manufacturing and polishing techniques, require more precise geometric end-face parameters with RLs of 65 dB or better.

An APC connector, by virtue of its spherical angular end-face, produces an extremely high-performance fiber-to-fiber interface. However, this alone cannot guarantee fiber core-to-core optimum alignment or correct physical contact. Well designed, high quality connector components and keying features are also required to achieve the best possible fiber core-to-core alignment and physical contact. One aspect of geometric (interferometry) measurements is the distance between the apex of the ferrule end-face and the center of the fiber core. This distance is known as the Apex Offset and is set to a maximum of 50 µm in accordance with industry standard specifications, IEC 60874-14-n and Telcordia GR-326-CORE issue 4, section 4.4.5.n.

In theory, the mated ferrules with centered Apex Offsets should have perfect fiber core-to-core connections and alignment, with no air gap. However, an air gap can be introduced with a large Apex Offset, resulting in high Insertion Loss (IL) and low RL.

2.0 Terms and Definitions

Apex Offset

Defined as the linear distance (in microns, µm) between the center of the fiber or fiber hole and the highest point on the ferrule end-face.

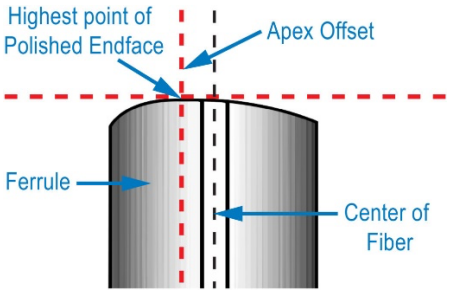

Figure 1: Apex Offset

Radius of Curvature (RoC)

Defined as the radius (in millimeters, mm) of the best fitting sphere over the defined Fitting Area.

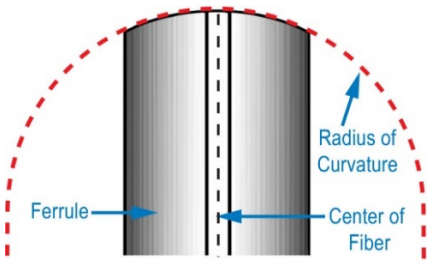

Figure 2: Radius of Curvature

UPC vs APC Polish

Typically, APC connectors have a key notch for a proper angles alignment.

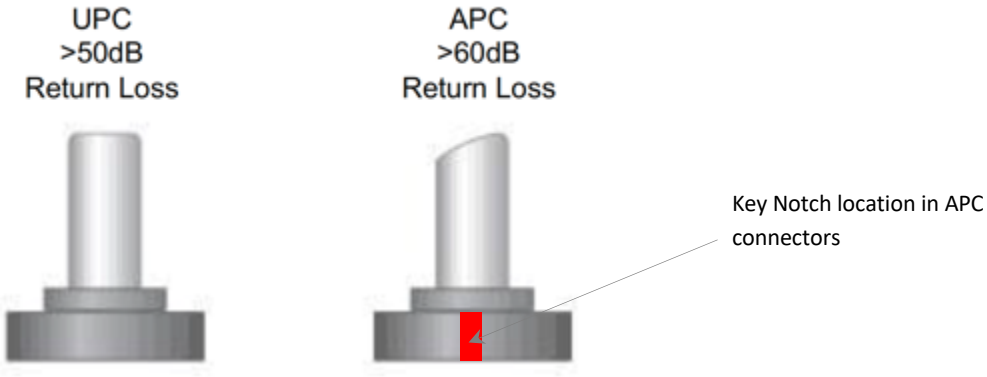

Figure 3: UPC and APC Polishes

Ferrule and Ferrule Flange

Ferrules are the key subcomponent within fiber optic connectors that house and protect them. Ferrule flange is a precision metal holder for a zirconia ceramic cylinder that aligns mating fiber cores for optimum transmission of the optical signal.

Figure 4: Ferrule and Ferrule Flange

APC Connector Keys with respect to the angle

With APC ferrules, the angled surface must be specifically oriented relative to the connector key, otherwise the two angled connectors would never mate properly upon physical contact. FC/APC and SC/APC ferrule angles are oriented specifically relative to the connector key. The angle most commonly faces to the right (highest angle point) of the key.

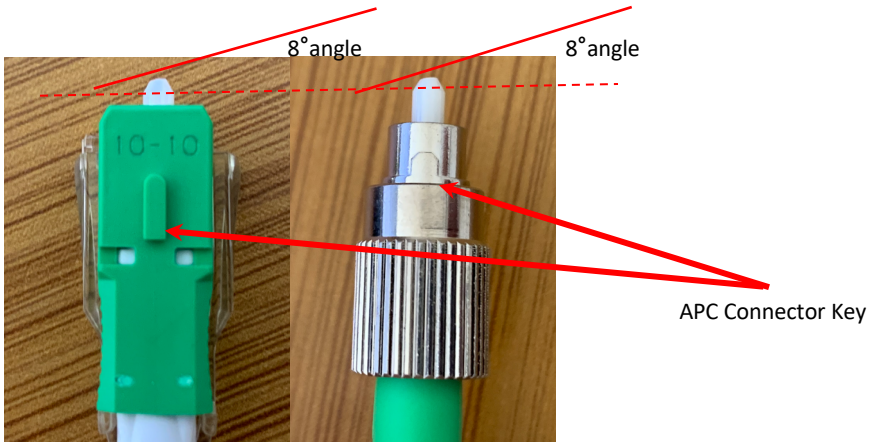

Figure 5: APC Angle with respect to Key

Key Error as an Interferometric Parameter

Key Error is any apex offset in the vertical axis caused by an error due to ferrule rotation with respect to the connector's key. It can be caused by a loose key notch in the polishing fixture or adapter and due to dimensional tolerances of the ferrule flange with respect to the inner connector housing. Key Error commonly results from the significantly larger widths of the polishing fixture key notches relative to the connector key and/or from the result of poor-quality connector components, such as plastic inner housings, which do not hold the ferrule firmly in place and in the proper orientation relative to the connector's key.

Interferometry Fringe showing Apex Offset

Figure 6 depicts a typical image of a ferrule end-face during interferometry measurements.

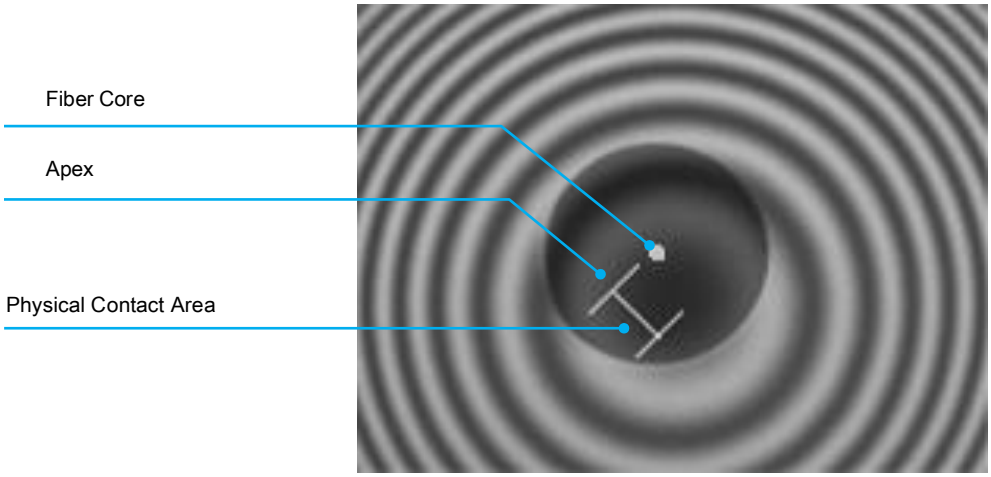

Figure 6: Interferometry Image showing Apex Offset

0 Apex Offset (UPC Ferrule)

Figure 7 depicts a UPC connection withthe Apex of the polish at the center of the fiber.

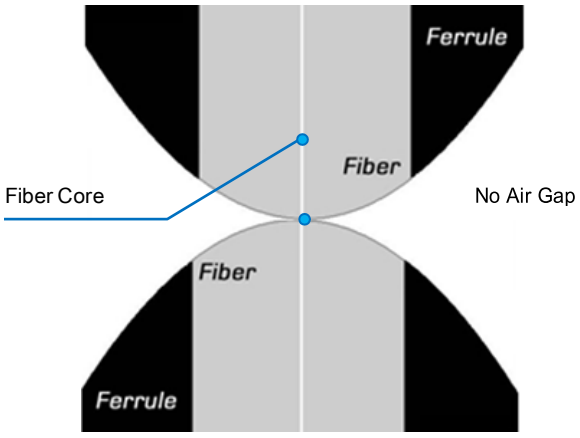

Figure 7: Zero Apex Offset in perfect Physical Contact

High Apex Offset Created an Air Gap (UPC Ferrule)

Figure 8 depicts two mated UPC ferrules with poorApex Offset, resulting in an air gap and, consequently, poor IL and RL performance.

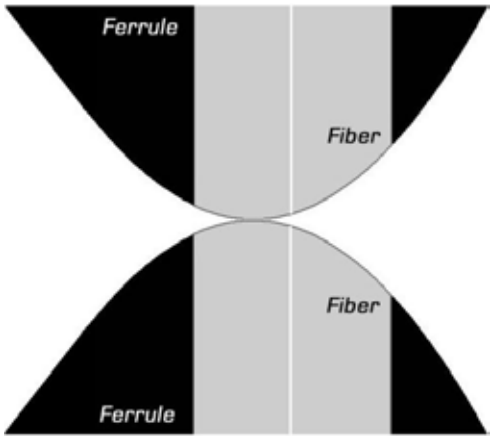

Figure 8: High Apex Offset results in an Air Gap

3.0 Angle Physical Contact (APC) vs. Physical Contact (PC)

Typically PC or Ultra PC (UPC for even tighter physical contact) connector ferrules of Ø2.5mm have a spherical end-face polish, with a Radius of Curvature (RoC) of 10 – 25 mm, and an Apex Offset ≤50 µm, as specified in Telcordia GR-326, IEC, and TIA/EIA industry standards. In contrast, Ø2.5mm APC connectors have an angled polished end-face (typically at 8°), with a smaller RoC of 5 – 12 mm, and the same Apex Offset of ≤50 µm, in accordance with the same industry standards.

In addition to an angular end-face and a smaller RoC, APC connectors also measure a value called Key Error. The Key Error parameter is shown by Interferometers as a measure of ferrule rotational movement (expressed in degrees) and is seen as a vertical shift in the Apex Offset. Apex Offset shifts result from a deviation in the end-face angle of 8°. In simple terms, Key Error displays the direction of the offset. This direction can be visualized as a clock hand with 12 o'clock representing 0° and 6 o'clock representing 180°. The closer the Key Error value is to zero, the better the physical contact will be between mating ferrules. Thus, the Key Error measurement is designed to measure the rotational orientation of the angled end-face with respect to the physical key on the connector housing. This parameter value is also used for refining APC polishing processes.

APC connectors incorporate a keying feature by design to minimize rotational movement of the ferrule to ensure proper physical contact between the two angled surfaces. Keying features in ferrule flanges and connector keys have some tolerances. Key Error can result not only from poor connector and ferrule design, but also from polishing fixtures that allow for a slight rotation of the ferrules and polishing processes that have an imprecise fixture angle value. Key Error can also result from a measurement error in the interferometer itself, if the insert fixture has loose key tolerances. Any rotation of the ferrule angle with respect to the connector key, regardless of the cause, will weaken the physical connection by introducing an air gap between the mated angled connectors pair.

During interferometric measurements, the APC interferometric insert fixture has a nominal angle tilt of 8.00° and a key notch for securing an angled connector key. This fixture does not rotate the apex around the axis of the fiber (as with PC connectors). Instead, a slight connector rotation within the fixture results in an apex change with a large vertical movement on the monitor. This occurs due to limitations in the Reflective Interferometric measurement when fringe density becomes too high for the CCD camera to resolve due to the fixture angle tilt.

In summary, the potential causes for variations in Key Error, which cause Apex Offset in APC connectors, are polishing equipment, polishing processes, interferometric equipment, and poor connector design. Today, it is possible to have a quality presize equipment and refined processes. This leaves the only significant variable to improve which is the APC connector design. The goal is to maximize physical contact by preventing ferrule rotation with respect to the inner key of the APC connector. As such, any freedom for the ferrule inside the inner housing or in the floating ferrule flange tolerances is undesirable.

Therefore, not all APC connectors are created equal. Depending on the precision of the connector parts used, some connectors are less repeatable than others in achieveing a full physical contact. Although it is possible to minimize rotation between the connector's outer key and the adapter keyway, it is difficult to reduce movement arising from rotation between the connector housing's inner opening that houses the ferrule flange. This rotational freedom, although typically very small, influences the Apex Offset and significantly reduces repeatability of physical contact to the order of 10's of microns.

For many years, the fundamental role that the Key Error parameter has on the Apex Offset was not well understood, so it had been somewhat overlooked and even ignored, with the focus instead placed almost solely on end-face angle accuracy. We now know the importance of minimizing Key Error in the APC connector design.

4.0 The Importance of Key Error

Manufacturers have invested significant resources in high quality polishing equipment and towards refining polishing processes to produce the best polish and end-face geometry for APC Connectors. While this approach is not wrong, it only addresses one of the variables that affect Apex Offset and the end-face angle.

In order to improve Apex Offset repeatability, resources and focus must also be directed towards connector design implementations that improve Key Error and Key Error repeatability, which can significantly alter Apex Offset repeatability.

Even if the polishing process produces end-faces with very goodApex Offsets, poorly designed connectors with bad Key Error repeatability can potentially change the Apex Offset by more than 30 µm during mating repeatability. This means that a connector with an Apex Offset of 30 µm (within specifications) can potentially have an Apex Offset of 60 µm, 10 µm above the industry standard specification of 50 µm. This produces fiber misalignment, resulting in poor IL and RL performance.

When selecting an APC Connector, it is critical that the Key Error repeatability be given just as high a priority as Apex Offset and end-face angle. The APC connector manufacturer should not intentionally hold the ferrules loose to allow two mating ferrules to rotate for best fit. Poorly made connectors have keys that do not fit keyways properly or have tolerance issues between keys and keyways. Finally, Key Errors can be caused by the ferrule not being held correctly inside the inner housing.

5.0 Solution

SENKO has found and demonstrated how critical it is to minimize ferrule rotation and to keep the key error repeatability as small as possible. This can dramatically change the apex offset repeatability of an APC connector.

The rotation around the axis of the ferrule of SENKO's new Premium SC APCconnector has been drastically minimized by maintaining tight tolerances on the ferrule key dimensions and unique ferrule flange design. This has significantly improved Key Error and Apex Offset repeatability.

The new Premium SC APC connector series was developed with these improvements in mind, enabling them to exceed industry standard requirements.

A comparison of SENKO's new Premium SC APC connector with highquality competitors during testing are shown in the Table 1 below:

Table 1. Apex Offset Comparison between SENKO SC/APC and two competing SC/APC connectors

New SENKO SC APC Premium

Apex Offset Av Δ (µm)	Key Error Av Δ (°)
2.31	0.033

From 80 measurements.

High Quality Competitor A

Apex Offset Av Δ (µm)	Key Error Av Δ (°)
8.18	0.109

From 120 measurements.

High Quality Competitor B

Apex Offset Av Δ (µm)	Key Error Av Δ (°)
6.83	0.086

From 80 measurements.

Notes:

* Key Errors of 0.1° can affect Apex Offset repeatability by more than 15 µm. Key Errors > 0.05° can affect Apex Offset by up to 10 µm.

** Both wet and dry cleaning of the ferrule end-face was performed beforeeach Apex Offset measurement to more accurately simulate in-the-field usage.

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