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White Paper | JUN 2020

QuPC® Connectors - Optical Interconnect for Quantum Networks

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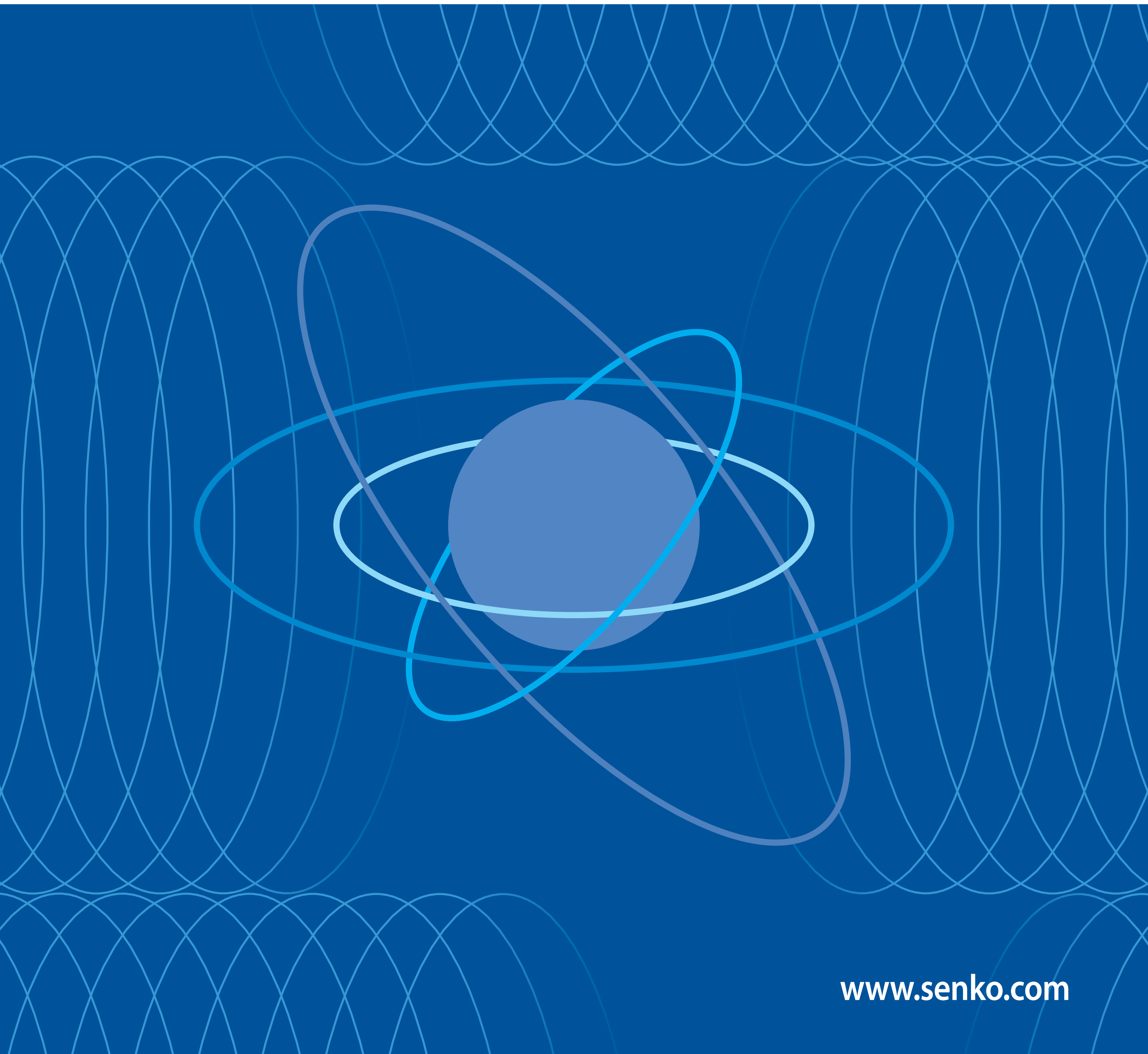

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Introduction

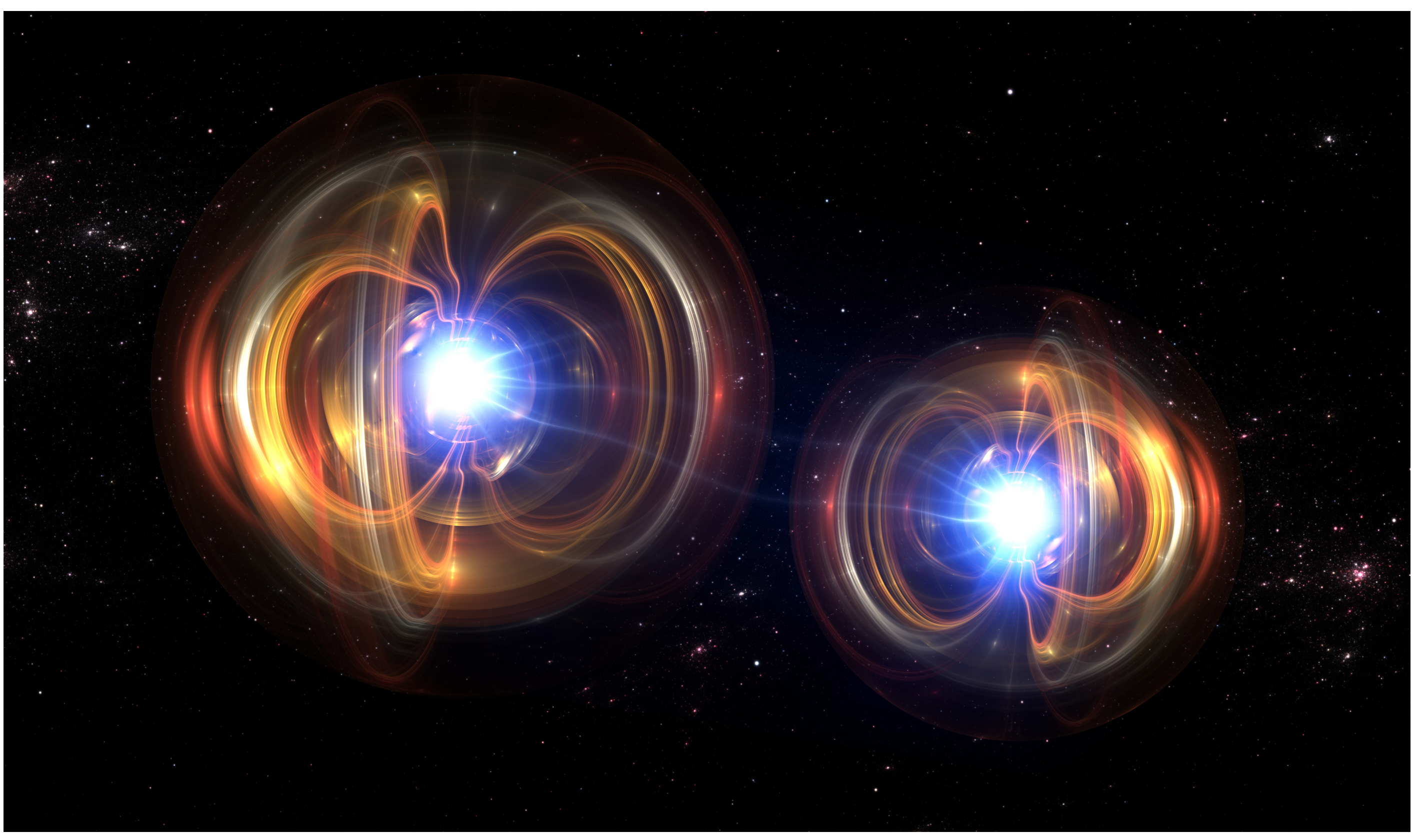
Data is an important asset to any organization across the globe. Investment in Information Technology (IT) security systems is increasing with more organizations adopting Cloud solutions to manage everyday operations from data repositories to running virtual desktops. Some of the key priorities for organizations are protection of intellectual property, critical infrastructure, customer information, and capital controls. Cyber-attacks and data breaches are expected to increase with the expansion of computer networks. One of the most difficult forms of data security breach to detect is eavesdropping, also known as sniffing or snooping attacks. Eavesdropping occurs when an attacker intercepts a weakly secured connection between a client and server and taps into the secure traffic passed between them. The attacker can then install a network monitoring software in any device in the network between the transmitting device and the receiving device. Device monitoring within a larger network becomes harder to detect. There are many data security approaches such as data encryption, encryption key management, and tokenization, but as these means of safeguarding network data become more sophisticated, so too do the means of intercepting it. In particular, the emergence of quantum computers, which are expected to be able to solve mathematical problems that cannot be solved using conventional computers, inevitably presents a significant threat to cyber security and attacks the foundations of today's cryptography. Quantum Key Distribution (QKD) is a new method of securing encryption and authentication by exploiting the quantum effects of "superposition" and "entanglement" to enable the exchange of secret symmetric cryptographic keys, which are secure, even against eavesdropping attempts powered by quantum computing.

As the technology eco-system for QKD, quantum computing and quantum measurement continues to grow at an accelerated rate, international standards will soon need to be introduced to define conditions for quantum networks. The International Telecommunication Union (ITU) has already started to address the stringent requirements for future quantum networks; a new ITU standard, "ITU Y.3800 - Overview on networks supporting quantum key distribution", describes the basic conceptual structures of QKD networks as the first in a series of emerging ITU standards on network and security aspects of quantum information technologies. Other international standards organizations, such as the IEC and ISO, are expected to follow suit over the coming years.

Principles of Quantum Superposition and Entanglement

Particles (e.g. photons or electrons) have physical properties such as position, spin, polarization, and momentum, which are described by a mathematical construct called a "wave function". According to quantum mechanics, prior to observation, a particle may have many different states at the same time, thus existing in a state of "superposition". It is only when the particle is observed through measurement, that the particle's wave function "collapses" to reveal a single state. For example, an unobserved particle could have a balanced superposition of both a clockwise and anti-clockwise spin, that is to say there will be a 50% chance that the particle will have one state or the other when measured. Once measured, however, subsequent measurements (in an ideal system without other disruptive factors) will always reveal the same state, therefore the act of observing has caused its wave function to collapse into one of the states.

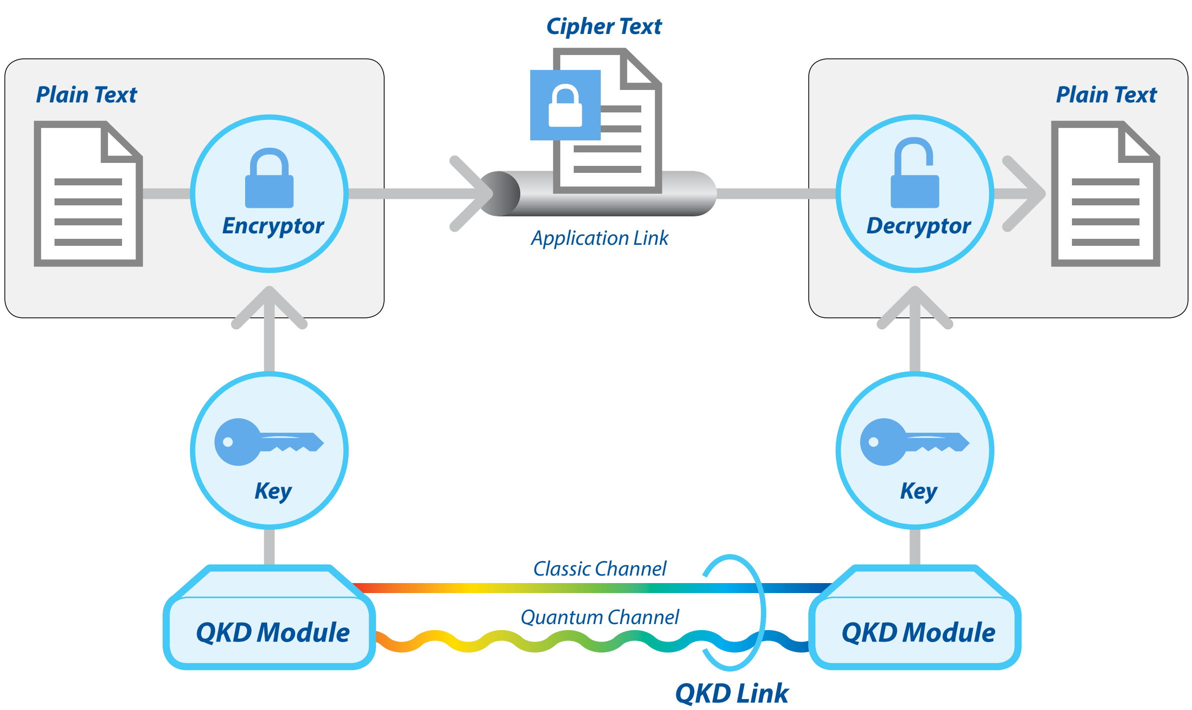
Particles can become "entangled" when a pair, or group, of particles is generated or share the same special proximity in a way that their quantum states become linked. For example, if you have a pair of entangled particles that are generated with the condition that their total spin is zero, and one of the particles is later measured to have a clockwise spin, then, from that immediate point, the other entangled particle, if measured, would always be revealed to have a counter-clockwise spin, regardless of how far apart these two particles may be separated. Therefore the wave function of the entangled particle system would be said to have collapsed with the measurement of the first particle. This property of entanglement can be used to create extremely secure communication links or form an integral part of a quantum computer or quantum measurement network.



Quantum Key Distribution (QKD)

Quantum Key Distribution (QKD) provides procedures for generating and distributing symmetrical cryptographic keys with information security based on the quantum behavior of photons. QKD is not a standalone security feature, but a complementary technology and service for communication networks. Keys generated by QKD modules that implement the QKD protocol can be used by any cryptographic applications that use symmetric keys such as One Time Pad (OTP), Hash Based Message Authentication Mode (HMAC), and Advanced Encryption Standard (AES). QKD can exploit either the measurement of single photons (BB84 protocol) or the measurement of entangled photon pairs (E91 protocol) to derive a random string of numbers used to form a secure quantum key. The statistical results of the measured photons indicate whether the photon has been intercepted or not.

The main challenge of introducing QKD into existing communication networks is the requisite change to the network infrastructure and cryptographic protocols. QKD technologies have unique features and restrictions, such as the requirement for point-to-point links and ultra-low loss, "quantum" channels.



The basic elements of a QKD communication system are the transmitter and receiver (QKD modules), and a QKD link between them comprising a Classical Channel and a Quantum Channel. The Classical Channel is used for data exchange between the QKD modules, while the Quantum Channel transmits quantum signals such as single or entangled photons, from which the cryptographic keys are derived.

QuPC Connectors for QKD Applications

Over the 2020's, QKD, quantum computing and quantum measurement applications are expected to gain traction. Central to these applications is the requirement to send single or entangled photons over optical networks without "decoherence". Decoherence, in this respect, refers to the collapse of the photon wave function, and can be caused by direct measurement or by disruption to the photon propagation due to aberrations (imperfections) in the optical conduit (optical fiber and connectors). QKD protocols try and account for decoherence due to environmental factors, such as poor quality of the optical fiber and imperfections in the optical connector, however if these are too great, QKD becomes less useful. The chances of transmitting a photon from transmitter to receiver without disruption, absorption or decoherence through other means, go down as the length of the Quantum Channel increases and the quality of the Quantum Channel (i.e. optical fiber and connectors) decreases.

The emerging field of quantum communications is therefore expected to fuel demand for a new generation of lower loss optical cables and connectors, which will allow larger proportions of single or entangled photons to propagate over optical networks without decoherence, thus improving the efficiency of the quantum optical network. Given that the power of a single photon can be of the order of -100 dBm, transmission over longer Quantum Channel distances represents a considerable challenge and thus the optical losses in the Quantum Channel must be minimized. To address this, SENKO has developed a new grade of connector that surpasses even the most stringent IEC connector grade. SENKO's "QuPC" Connector exhibits insertion and return losses similar to a fusion splice.

Insertion Loss	Return Loss
≤ 0.1dB average	≥ 60dB
≤ 0.2dB max in 97% of splices	

Insertion & Return Loss of Fusion Splices as per IEC Standards IEC 61300-3-6 and IEC 61300-3-7

The two main areas of improvement required to increase connector performance are the material quality and manufacturing process.

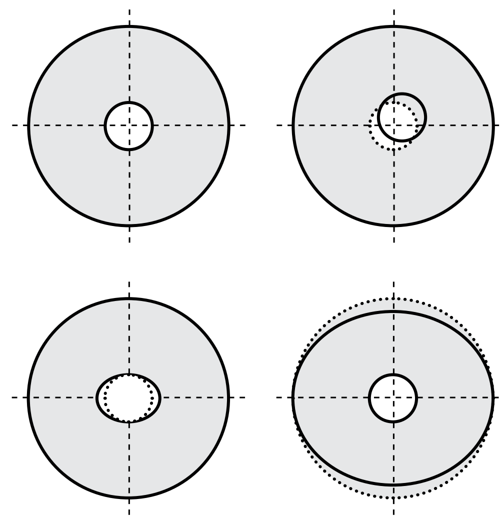
Material

The coherent single or entangled photon string is transmitted through an optical fiber network. This makes the optical fiber itself an important factor in improving the connector quality. Light does not propagate through the whole optical fiber, but only through the core, therefore the relative dimensions of the core and cladding of the optical fiber will have a big impact on the connector quality. There are three main parameters that must be tightly controlled: 1) the core-cladding concentricity, 2) core ovality, and 3) cladding ovality.

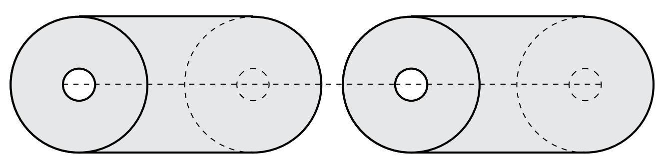
The core-cladding concentricity is the measure of how symmetrically central the position of the core is with respect to the cladding. The deviation of fiber core from the center of the cladding is known as the core-cladding concentricity error, which all fibers exhibit, to some degree. In order to produce a QuPC Connector, this error must be minimized. Core ovality and cladding ovality is the degree of deviation of the core and cladding from being a perfect circle. An oval core will cause imperfect core connections, which will increase insertion loss and back reflection, while an oval cladding will cause high ferrule concentricity error.

The ferrule is the part of an optical connector, which holds the optical fiber in place and is physically mated to another ferrule to make a continuous pathway for light to pass from the core of one fiber to the core of another. The concentricity of a ferrule is the measure of how symmetrically central the position of the ferrule hole (or bore) center is relative to its circumference. It is also crucial to minimize the size of the ferrule hole diameter. A larger hole will cause a high variability in the position of the optical fiber, which will then lead to increased fiber core misalignment. The diameter of a Single Mode optical fiber is 125µm, thus the ferrule hole must be reduced to a diameter that is as close to the fiber diameter as possible accounting for tolerances and additional space for epoxy adhesive to secure the optical fiber.

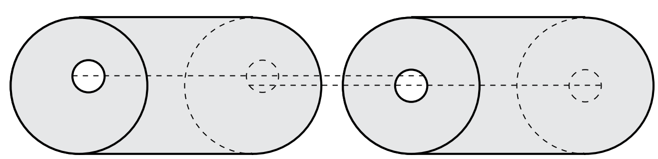
Core and Cladding Concentricity and Ovality



Perfect Ferrule Concentricity

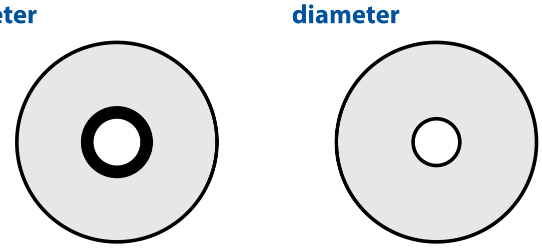


Ferrule Concentricity Error



Large ferrule hole diameter

Minimized ferrule hole diameter



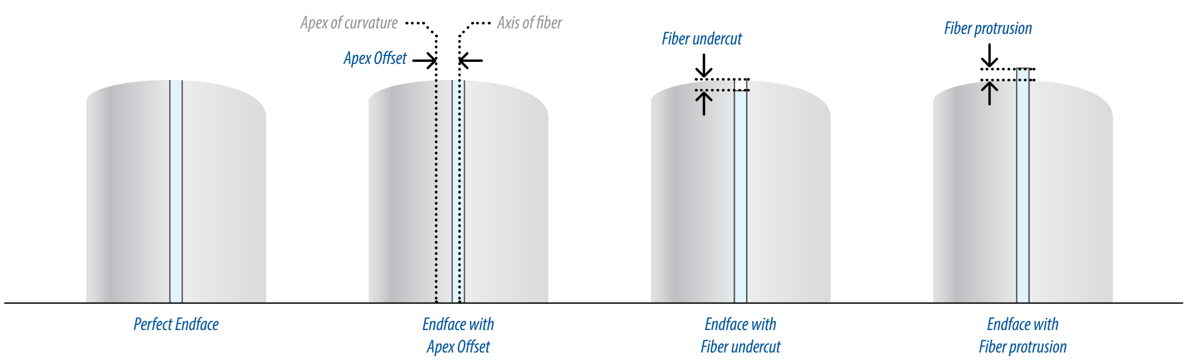
Manufacturing

Even with high quality optical fiber and ferrule components with tight tolerances, the connector manufacturing processes must also be tightly controlled to produce high quality connectors.
One of the connector manufacturing processes is the mixing of epoxy and curing process. There are multiple controlled steps to ensure proper management, application, and curing.

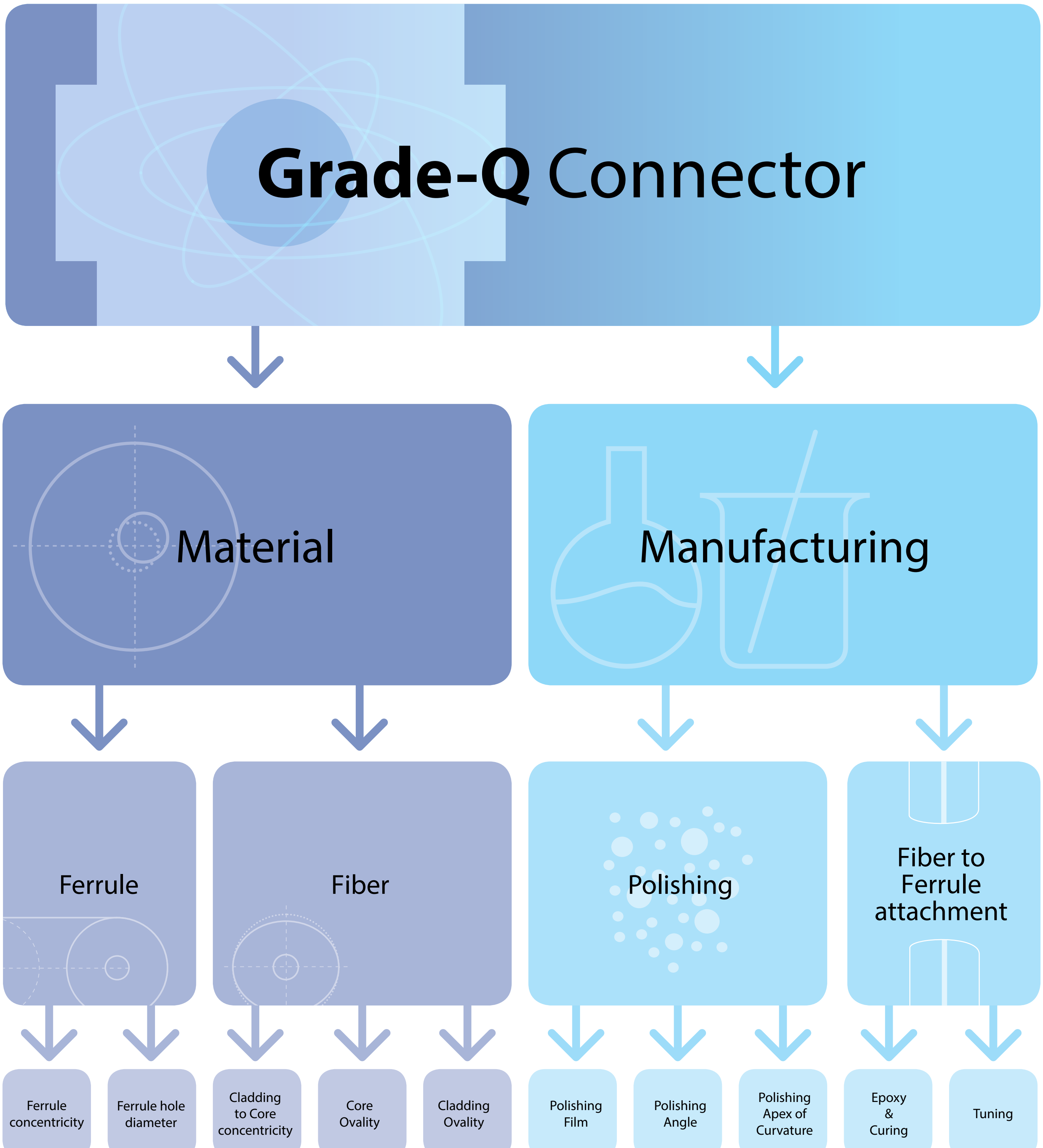
STORAGE	Epoxy has a shelf life and must be stored in a specific temperature range depending on the type of epoxy used.
MIXING	Most epoxy used is a two-part mixture where the correct ratio must be used. The mixing process must be controlled to eliminate any air bubbles because they will expand during the curing process, which cause imperfect fiber to ferrule adhesion.
APPLICATION	Once the epoxy is mixed, it has a short pot life where it must be used as it will start to crystalize. Using epoxy that has started to crystalize can cause fiber microbends inside the ferrule. The right amount of epoxy must be inserted into the ferrule hole. Too little will cause imperfect fiber to ferrule adhesion, while too much will cause an overspill onto the connector ferrule.
CURING	The temperature range and duration of the curing process must be suitable for the type of epoxy used. A curing temperature that is too low will result in incomplete curing while a temperature that is too high can cause air bubbles to form, both of which will lead to imperfect fiber to ferrule adhesion.

Improvements to the ferrule polishing process are determined by the careful adjustment of the polishing pad, level of applied pressure, the type of polishing film, accuracy of the polishing angle and the polishing apex of curvature. These factors control the granularity and smoothness of the connector end-face, reduce the apex offset, and centralize the apex of curvature, all of which serves to reduce the air gap between the optical fiber cores being connected.

Connector end-face parameters

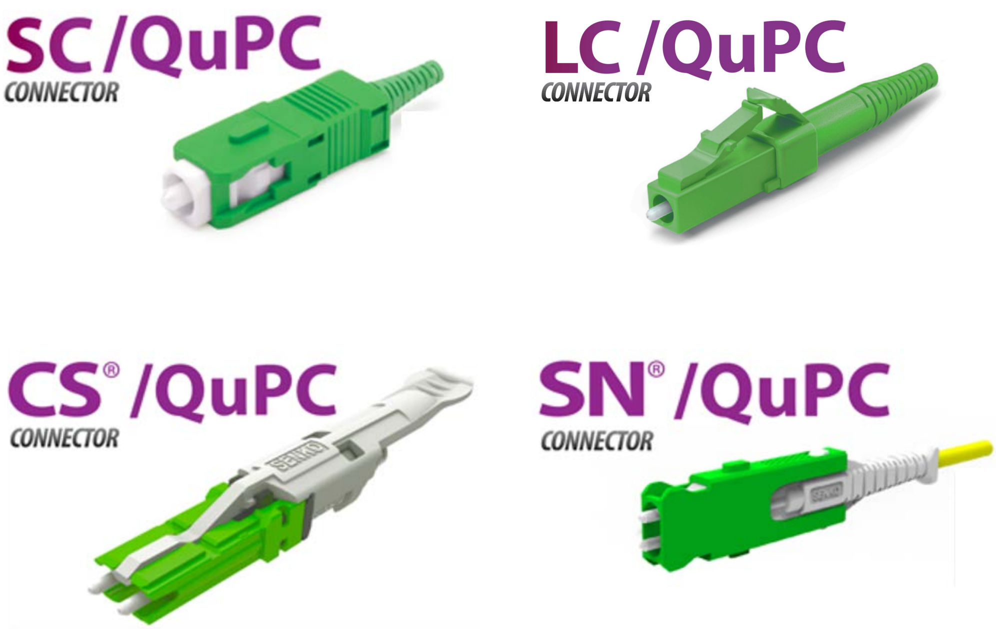


As it is impossible to perfectly center the fiber core in the ferrule due to manufacturing tolerances, a connector tuning process is used to correct concentricity errors caused from using ferrules with larger hole diameters. Although the quality control measures to improve the optical performance of SENKO's QuPC Connector include reduction of the ferrule hole diameter, tuning can still further improve the connector's performance. The tuning process involves assembling the optical fiber connector while measuring the signal characteristics through the connector and examining its physical properties to determine the optimal position of the fiber and ferrule in the connector.


Grade-Q Connector
Material
Manufacturing
Ferrule
Fiber
Polishing
Fiber to Ferrule attachment
Ferrule concentricity
Ferrule hole diameter
Cladding to Core concentricity
Core Ovality
Cladding Ovality
Polishing Film
Polishing Angle
Polishing Apex of Curvature
Epoxy & Curing
Tuning

SENKO QuPC Connectors

With the improvements in optical fiber, connector ferrules, and manufacturing processes, SENKO has developed the QuPC connector, which has a connector loss performance that is superior to that of a fusion splice. The connectors feature a premium super low insertion loss of less than 0.1dB, and an optical return loss of more than 80dB. This far exceeds the ITU specified performance for a fusion splice. Aligned with future development of higher density connectivity, the QuPC connectors are also available in CS and SN connector form factors.



SENKO's QuPC connector range

Insertion Loss

$\leq$ 0.1dB

Return Loss

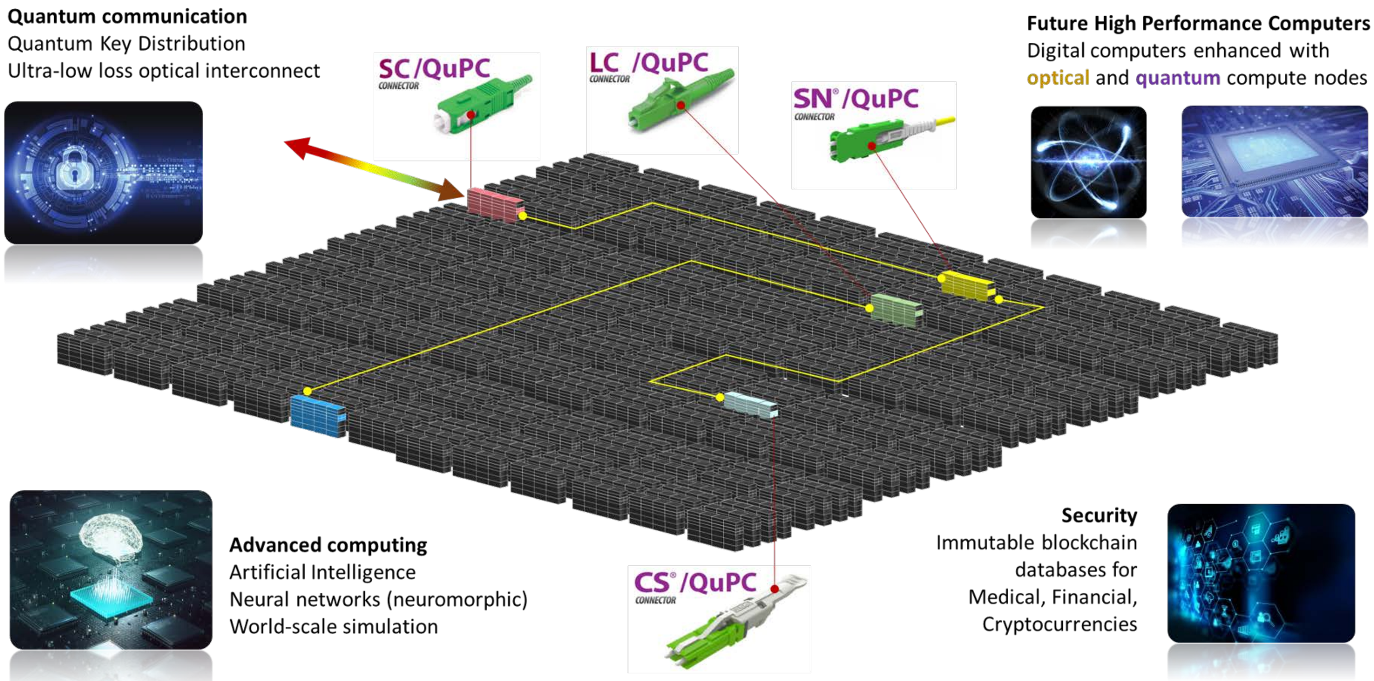
$\geq$ 80dB

Connector Maintenance

As the connector end-face must be protected against scratches or pitting to maintain its low-loss performance, the recommendation is to use SENKO's non-abrasive gel based cleaner. The use of regular connector hygiene products such as cassette cleaners and click cleaners require the connector end-face to be pressed against a cleaning tape, which then wipes away any contamination. However, if there are any solid contaminants present on the end-face, such as dust, the act of wiping can cause micro-scratches on the connector end-face.

Summary

Optical interconnect is entering a "Third Age", in which optical links are replacing copper interconnect over even shorter distances, due to increasing bandwidths and decreasing loss margins, now even moving into the system enclosure itself and up to the chip. Further to that, the ICT community is now recognizing the need for Quantum Networks for QKD, quantum computer and quantum measurement interconnect, and international standards organizations are preparing to support this. With its QuPC optical connector range, Senko has produced an optical connector that is able to exceed the performance of an optical fusion splice and is virtually undetectable by an OTDR. Over the next ten years, hyperscale data centers and exascale supercomputers will increasingly incorporate quantum communication and quantum computer nodes to complement their value proposition, for example through quantum computing as a service (QaaS) or hyper-secure inter-data centre interconnect. SENKO is leading the international connector community into the era of quantum connectivity.



Hyperscale data center and supercomputer with quantum computer, communication and sensor nodes interconnected by QuPC links

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3. Quantum Networks, https://en.wikipedia.org/wiki/Quantum_network

Biography

Dr. Bernard HL Lee is currently the Director of Technology & Innovation at SENKO Advanced Components. He started his career in optical communications when he was appointed as a Senior Research Office for the European Union IST project known as DAVID in 2000. In 2003, he joined Telekom Malaysia R&D where he has held various technical and management positions there including the Head of Photonic Network Research and also Head of Innovation and Communications. Bernard then joined the parent company, Telekom Malaysia (TM) in 2010 as the Assistant General Manager of the Group Business Strategy Division where he oversees the company's business direction. Bernard obtained his BICSI RCDD accreditation in 2016 and currently serve as the Malaysian Country Chair for BICSI Southeast Asia. Bernard is also a member of the International Electrotechnical Commission (IEC) standards subcommittee on fiber optic interconnecting devices and passive components (SC86B) and a Chartered Engineer (CEng)

Dr. Richard Pitwon is the CEO of Resolute Photonics with more than 20 years transformational expertise in optical and photonic system interconnect, integration and architectures for hyperscale data centre, HPC, 5G and IoT data-communications applications. At Xyratex (2002) and then Seagate (2014), he managed internal and international, multi-million-dollar collaborative research and development programmes, skilled in building multi-disciplinary teams to deliver advanced system solutions and coordinating across multiple geographies. He holds 54 patents in diverse fields, has authored over 50 peer-reviewed publications including 4 international standards and given over 70 public talks. He is the current chair of the IEC international standards subcommittee on fiber optic interconnecting devices and passive components (IEC SC86B) and principal UK standards expert (BSI) for optical interconnect, optical circuit boards, photonic integrated circuits and electronic assembly. He is a Chartered Engineer (CEng), Fellow of the IET (FIET), Fellow of the Institute of Physics (FInstP) and Senior Member of the IEEE (SIEEE).

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