WHITE PAPER

Expanded Beam Fiber Optic Connectors

1. Executive Summary

Conventional fiber optic connectors transmit optical signals by bringing two precision-polished Ferrule end-faces into direct contact - the Physical Contact (PC) method. While this approach delivers excellent optical performance in clean, controlled environments, it is inherently vulnerable to dust, moisture, and mechanical contamination. In military vehicles, shipboard systems, aircraft, and outdoor tactical environments, however, such contamination is unavoidable.

Expanded Beam (EB) connectors solve this problem at its root by replacing direct fiber-to-fiber contact with a lens-based, non-contact optical interface. A compact precision lens performs Collimation - gathering and collimating the light emitted from the fiber into an expanded beam - which then crosses a small Air Gap before being refocused by a second lens in the mating connector into the receiving fiber. Because the beam diameter at the interface is dramatically larger than the fiber core itself, small particles of dust, sand, or moisture have a far smaller relative impact on signal transmission.

L&KF's Expanded Beam connector portfolio - is designed for defense, aerospace, naval, and industrial customers who need dependable optical links in the field, without reliance on specialized cleaning equipment or trained technicians. is designed for defense, aerospace, naval, and industrial customers who need dependable optical links in the field, without reliance on specialized cleaning equipment or trained technicians.

2. Physical Contact (PC) Connectors, Principle and Limitations

In a Physical Contact (PC) connector, each optical fiber is bonded into a precision ceramic ferrule, and the ferrule end-face is polished to a sub-micron finish. When two connectors are mated, the ferrules are pressed together under spring pressure inside a precision Alignment Sleeve, bringing the fiber cores into direct contact. Under ideal conditions, this design achieves very low insertion loss - typically 0.2 to 0.3 dB - and, with an angled polish (APC), high return loss performance.

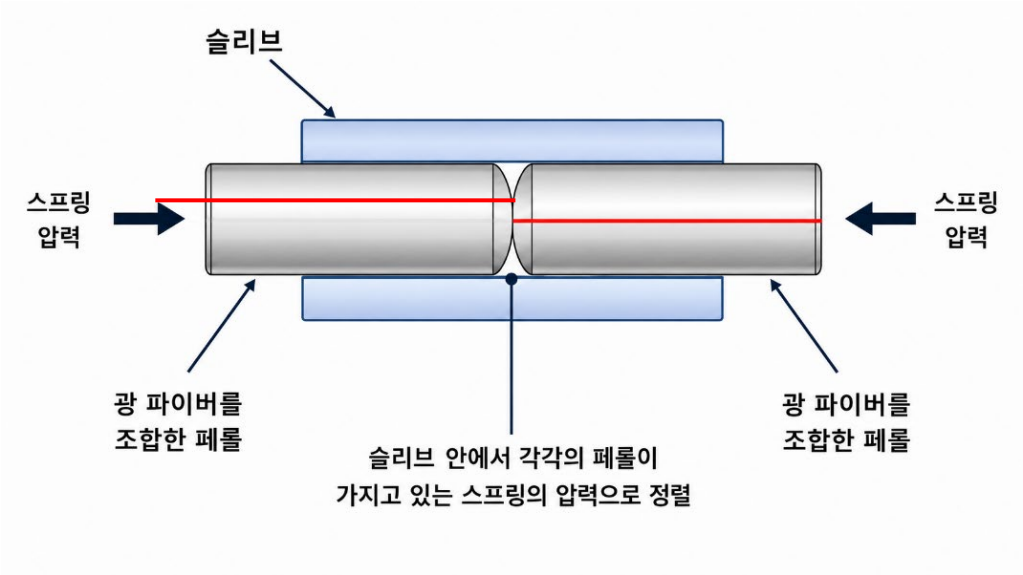

Figure 1 - Physical Contact (PC) optical interface - simplified schematic

2.1 Sensitivity to Contamination

The core diameter of a single-mode fiber is approximately 9 µm - smaller than a typical airborne dust particle. A single dust or grit particle lodged between two mated ferrule end-faces can be sufficient to block signal transmission entirely, or to scratch the polished surface and permanently degrade optical performance. Because the ferrule end-face is fully exposed whenever the connector is unmated, every field disconnect/reconnect cycle is an opportunity for contamination to enter the optical path.

2.2 Maintenance Burden

Restoring a contaminated Physical Connector to specification typically requires disassembly, inspection under a fiber end-face microscope, and cleaning with an approved cleaning solvent. If the ferrule end-face has been scratched or chipped, field cleaning cannot restore performance - the connector must be re-polished in a workshop, or replaced entirely. This level of intervention is impractical for field personnel operating under time pressure or without access to specialized equipment.

3. Expanded Beam (EB) Technology -- Operating Principle

Expanded Beam connectors eliminate the contamination problem at its source by removing direct fiber-to-fiber contact entirely. Light emerging from each fiber is captured by a small precision lens - typically a Ball Lens or a graded-index GRIN rod lens - which collimates and expands it into a wide, parallel beam. This collimated beam crosses a sealed air gap, reaches the corresponding lens in the mating connector, and is refocused back into the receiving fiber core.

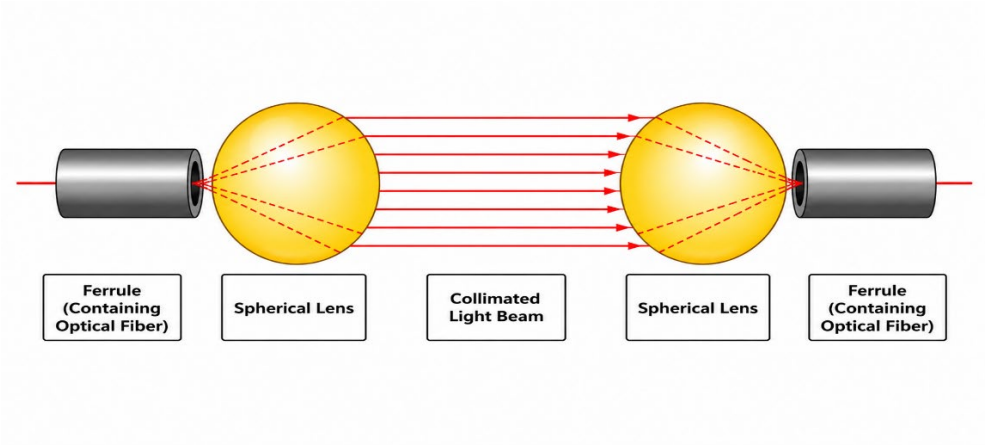

Figure 2 - Expanded Beam (EB) optical interface - simplified schematic

Because the optical path no longer depends on two polished surfaces pressing together under spring tension, there is no mechanical wear on the optical interface itself. The connector can therefore be mated and unmated thousands of times without any degradation in optical performance.

3.1 How Beam Expansion Reduces Contamination Sensitivity

The key advantage of beam expansion is one of relative Scale. For a single-mode fiber, the expanded beam at the lens interface can occupy an area approximately 2,000 times larger than the bare 9 µm fiber core; for multimode fiber, the expanded area is on the order of 150 times larger. A dust particle large enough to completely block a bare single-mode fiber core therefore intercepts only a tiny fraction of the much larger expanded beam, allowing the majority of the signal to pass through with minimal additional loss.

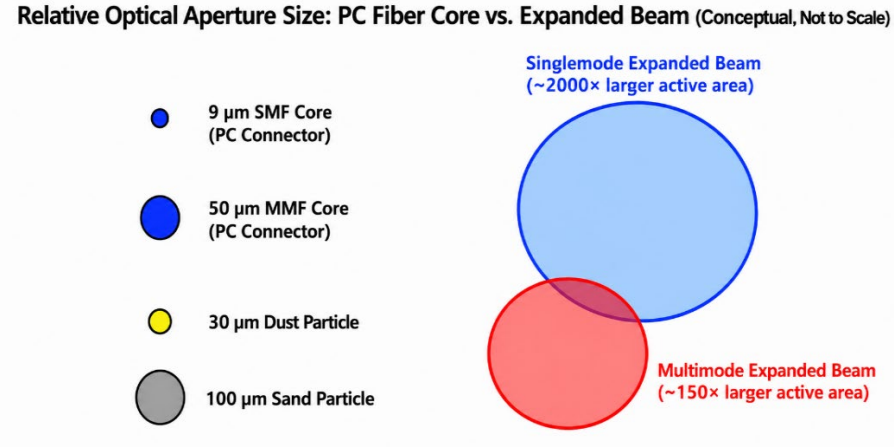

Figure 3 -- Conceptual comparison of optical Aperture sizes: PC fiber core vs. expanded beam. Illustrates why expanded beam interfaces are inherently less sensitive to fine particle contamination.

Illustrates why expanded beam interfaces are inherently less sensitive to fine particle contamination.

4. Why Contamination Sensitivity Matters in the Field

Military and industrial environments routinely subject connectors to conditions that bear little resemblance to a telecom equipment room. Vehicles operate in dust and sand; ships are exposed to salt spray and humidity; outdoor tactical links are connected and disconnected in mud, rain, and freezing conditions. In these environments, the key question is not whether a connector will encounter contamination, but how it performs once it does.

4.1 Sealed Optical Path

In an expanded beam connector, the critical interface between the optical fiber and the lens is sealed during manufacture, isolating it from the external environment for the entire product life. The surface exposed at the connector mating face - the lens itself - is typically a flat, hard, anti-reflection-coated window with no deep cavity or alignment sleeve to trap contaminants.

4.2 Simple Field Cleaning

Because the lens surface is flat and directly accessible, an expanded beam connector contaminated with mud, dust, or salt residue can normally be restored to service by simple rinsing and wiping - without disassembly, without specialized tools, and without risk of damaging the optical path. For field personnel who must rapidly re-establish a fiber link without access to a clean workspace, this is a significant operational advantage.

4.3 Consistent Performance Over Product Life

A PC connector's optical performance peaks when new and degrades progressively with each mating cycle, cleaning attempt, and contamination event - eventually resulting in unpredictable signal loss or complete failure. An expanded beam connector, by contrast, maintains essentially constant performance across thousands of mate/demate cycles and repeated exposure to harsh conditions, because the sealed optical interface does not wear or degrade in normal use.

5. Performance Comparison: PC vs. Expanded Beam

Both connector technologies have their place, and the right choice depends on the application's priorities. The table below summarizes the principal trade-offs based on general industry experience in defense and harsh-environment programs.

Insertion Loss	PC connectors typically achieve lower insertion loss (~0.2–0.3 dB) when new and properly maintained. Expanded beam connectors are somewhat higher (~0.7–1.5 dB typical), reflecting the additional lens interfaces in the optical path.
Return Loss	PC connectors with angled (APC) polish provide superior return loss performance, important for analog and wavelength-sensitive links. Expanded beam connectors have inherently higher back-reflection due to the air-gap and lens interfaces.interfaces.
Reduced Sensitivity to Dust & Debris	Expanded beam connectors hold a decisive advantage. The larger beam diameter makes the connection far less sensitive to fine particle contamination than a bare PC ferrule tip.
Field Cleanability	Expanded beam connectors can be cleaned by rinsing and wiping a flat lens surface. PC connectors require a dedicated cleaning set and inspection equipment, and disassembly is often required.
Mate / Demate Life	Because there is no mechanical wear on the optical surfaces, expanded beam connectors generally tolerate a greater number of mate/demate cycles without performance loss.
Long-Term Reliability in Harsh Conditions	Expanded beam connectors maintain consistent optical performance through repeated exposure to dust, mud, and moisture. PC connector performance is more likely to degrade progressively under the same conditions.
Contact Density	PC connectors generally achieve higher channel density within a given shell size, due to the smaller contact area of ferrule-based termini.

In summary: PC technology remains the preferred choice where minimum insertion loss and maximum channel density are the priorities and the operating environment can be reasonably controlled. Expanded beam technology is the preferred choice wherever the optical link must survive repeated field handling, contamination, and harsh environmental exposure without specialized maintenance -- precisely the conditions facing defense, aerospace, and naval platforms.-

6. Mechanical and Environmental Robustness

L&KF's Expanded Beam connector lines are built around qualified military shell platforms -- MIL-DTL-38999 Series III and MIL-DTL-83526 -- and fully inherit the mechanical and environmental qualifications of those shell families, including sealing, shock, vibration, and temperature performance.

6.1 Sealing and Water Resistance

L&KF Expanded Beam connectors on the MIL-DTL-38999 platform meet IP67. The MIL-DTL-83526-based Senior, Junior, and Mini series are qualified for submersion to 15 metres for 24 hours, in both mated and unmated condition. This level of sealing is achievable because the optical interface itself does not rely on a spring-loaded mechanism that must be kept dry to function.

6.2 Shock, Vibration and Drop Resistance

The connector lines are qualified to withstand repeated free-fall drops from 1.2 metres, sustained vibration across 10–500 Hz, and thousands of high-acceleration mechanical shock cycles - conditions representative of transport, handling, and operation aboard vehicles, aircraft, and vessels.

6.3 Operating Temperature Range

Depending on shell family, L&KF Expanded Beam connectors operate across temperature ranges as wide as −46°C to +85°C, with storage ratings extending to −57°C, supporting deployment from arctic to desert environments without special accommodation.

7. L&KF Expanded Beam Connector Product Line

L&KF Co., Ltd. offers a complete Expanded Beam connector portfolio designed for direct interoperability with existing MIL-qualified harnesses and equipment interfaces.

7.1 D38999 Expanded Beam Connector

D38999 Plug & Receptacle - MIL-PRF-28876 Rev. E compliant

Precision-machined to MIL specification, available in shell sizes 11 through 23 with 1 to 16 optical channels and six keying options, with full interoperability with all qualified 38999 connectors.

7.2 MIL-DTL-83526 Expanded Beam Connector - Senior / Junior / Mini

Expanded Senior - Hermaphroditic tactical connector for naval and field deployment

Fully Hermaphroditic tactical connectors qualified to MIL-DTL-83526, offered in Senior, Junior, and Mini package sizes .

8. Conclusion

Physical contact connectors remain an excellent choice where insertion loss and channel density are the dominant requirements and the operating environment can be reasonably controlled. For systems that must be operated - and maintained - in the field under conditions of dust, mud, saltwater, vibration, and repeated handling, however, the non-contact optical interface of Expanded Beam connectors offers a fundamentally more robust solution. however, the non-contact optical interface of Expanded Beam connectors offers a fundamentally more robust solution.

L&KF Co., Ltd. provides Expanded Beam connector solutions built on proven military shell platforms, combining the optical reliability of lens-coupled transmission with the mechanical and environmental performance demanded by defense, aerospace, naval, and industrial customers. Our engineering team is available to support specification review, custom configuration, and integration into existing harness designs.

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