Fibre Optic Connectors

Why expanded beam is essential in harsh environments

Abstract

Traditional physical contact fibre optic connectors have proved to be unreliable in harsh environment applications due to their sensitivity to dirt, dust, mud, water, oil and other contaminants. Expanded beam fibre optic connectors offer the solution. This paper explains the benefits of expanded beam over physical contact, and demonstrates how expanded beam connectors offer improved reliability in harsh environments.

Introduction

Physical contact connectors were originally designed for datacom and telecom systems, operating in benign environments such as telephone exchanges and data centres. As the name suggests, these connectors employ termini containing optical fibres which physically mate together under spring pressure within an alignment sleeve allowing the optical fibres to contact and make the connection. During assembly, the termini are polished using high precision polishing machines to provide the precise end-face geometry and sub-micron finishes necessary to achieve the required optical performance.

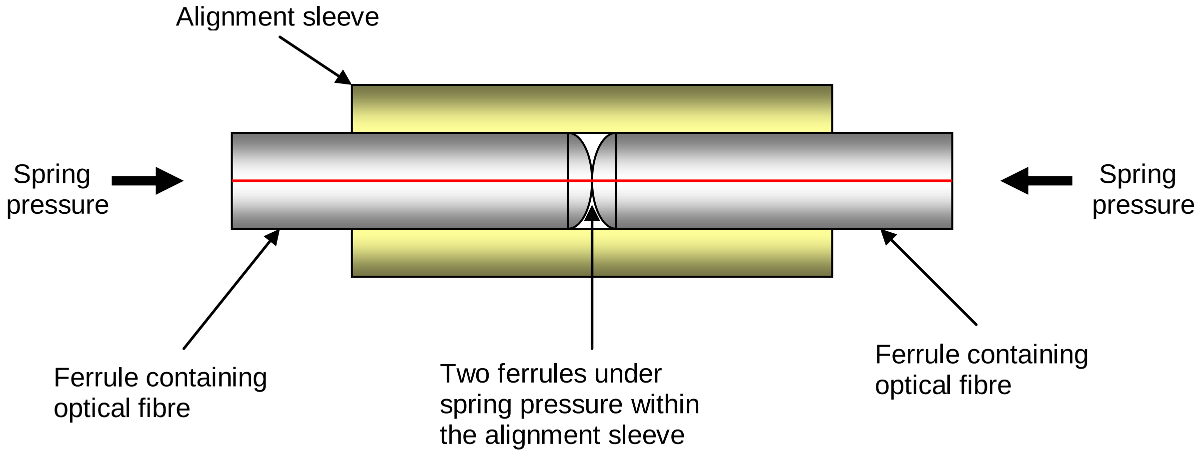
In recent years, these same termini have been incorporated into more rugged multi-way connectors in an attempt to provide harsh environment fibre optic connectors for civil and military aerospace, military ground applications, naval systems and offshore environments.

The fundamental drawback of physical contact connectors is that when in an un-mated state, the fibre optic end-face is exposed to the outside environment. Any contaminants present can degrade the sub-micron polished finish on the end-face when mated, and can cause the optical performance to deteriorate significantly particularly when in use or in high vibration applications. Often, even the process of attempting to clean the end-face can cause serious damage to the optical fibre, resulting in high attenuation and reducing system integrity.

Expanded beam fibre optic connectors have been designed specifically to operate in harsh environments. They utilise a non-contact technique where the fibre is fully sealed behind a lens. The lens effectively enlarges the active area of the fibre, thus providing a connector with greatly reduced dirt sensitivity and therefore higher reliability when used in adverse conditions. The air gap generated between the mated lenses ensures any debris present on the lenses do not cause damage during operation or vibration, providing a further level of ruggedness.

Physical contact Connectors

Physical contact method is shown below:



During a typical fibre termination, the ferrule end-faces are polished on a high precision polishing machine to achieve a radiused profile to allow the mating optical fibres to contact. The mating termini are held in position under spring pressure within a ceramic alignment sleeve. The ferrule end-face geometry and sub-micron polish finish are critical in achieving optimum optical performance.

In a harsh environment application, this type of connector has a number of draw backs:

1. The highly polished ferrule ends are exposed to the outside environment when the connector is in an un-mated state. This allows the fibre to become contaminated with dust, dirt, mud, water etc.

2. A dust particle as small as Ø9µm on a singlemode fibre core is enough to completely block signal transmission. A typical dust particle size is between Ø5µm and Ø40µm.

3. If a connector with dirty or contaminated termini is mated to another connector, the contamination is passed to those termini in that connector. Moreover, termini with damaged end-faces could permanently damage the mating termini.

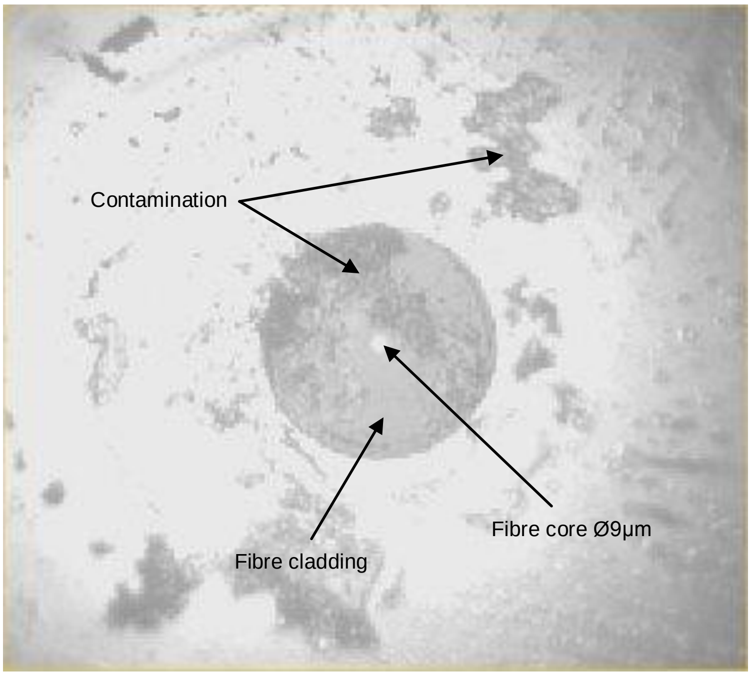
4. Because the termini are sprung loaded against each other, any abrasive particles trapped between them will be contained and abrade onto the optical fibre surfaces causing serious damage and high signal attenuation during its use.

5. Physical contact connectors often make cleaning of the termini difficult due to there being three components to the connection, (two termini and an alignment sleeve). Alignment sleeves are usually retained in the receptacle connector, resulting in the need to clean inside a deep narrow cavity. Often, connector disassembly is required to access the termini end-faces and alignment sleeves for cleaning.

6. Special cleaning materials are required to clean physical contact termini. Lint-free tissues, cleaning solvent and specialist cleaning swabs are essential. Further damage to termini can occur if the incorrect cleaning materials are used.

7. The termini in physical contact connectors are sprung loaded and therefore inherently difficult to water seal. Some physical contact connectors only seal when mated or if a protective cap is fitted.

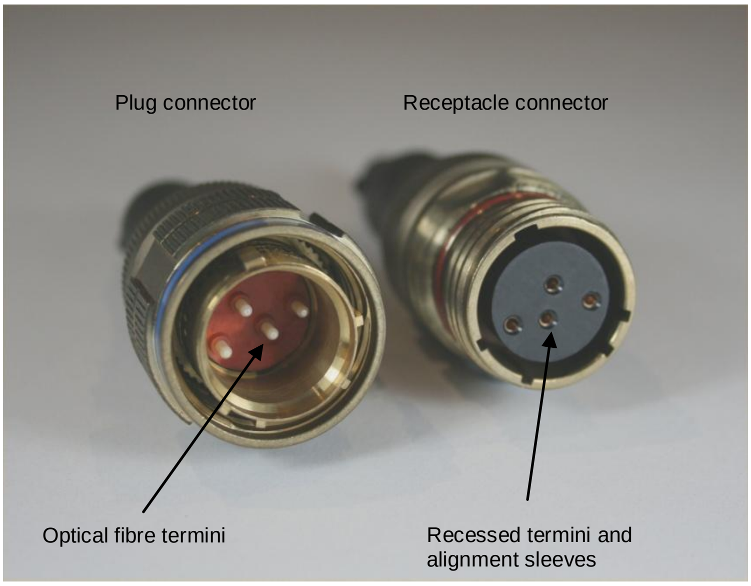
8. When in perfect condition, physical contact connectors give good optical performance, insertion loss of around -0.3dB and reflectance in excess of -45dB. However, the optical performance will degrade during normal usage in harsh environments and continue to degrade over the product life. High loss or complete signal failure can occur if the fibre core is damaged.



View on a physical contact termini end-face at 200x magnification showing typical contamination from dust and oily deposits.

For physical contact connectors an end-face inspection microscope is essential to check for contamination or damage.

Typical physical contact plug and receptacle connectors:



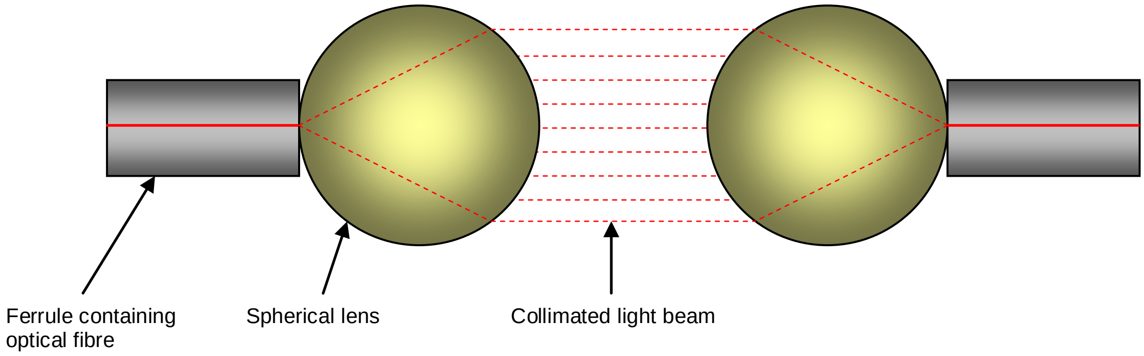
The plug connector termini are fully exposed and easily contaminated or damaged when un-mated.

The termini and alignment sleeves in the receptacle connector are recessed deep in the socket front, creating a dirt trap and making cleaning difficult.

Connector disassembly is required to properly clean the termini and alignment sleeves.

The Expanded Beam Principle

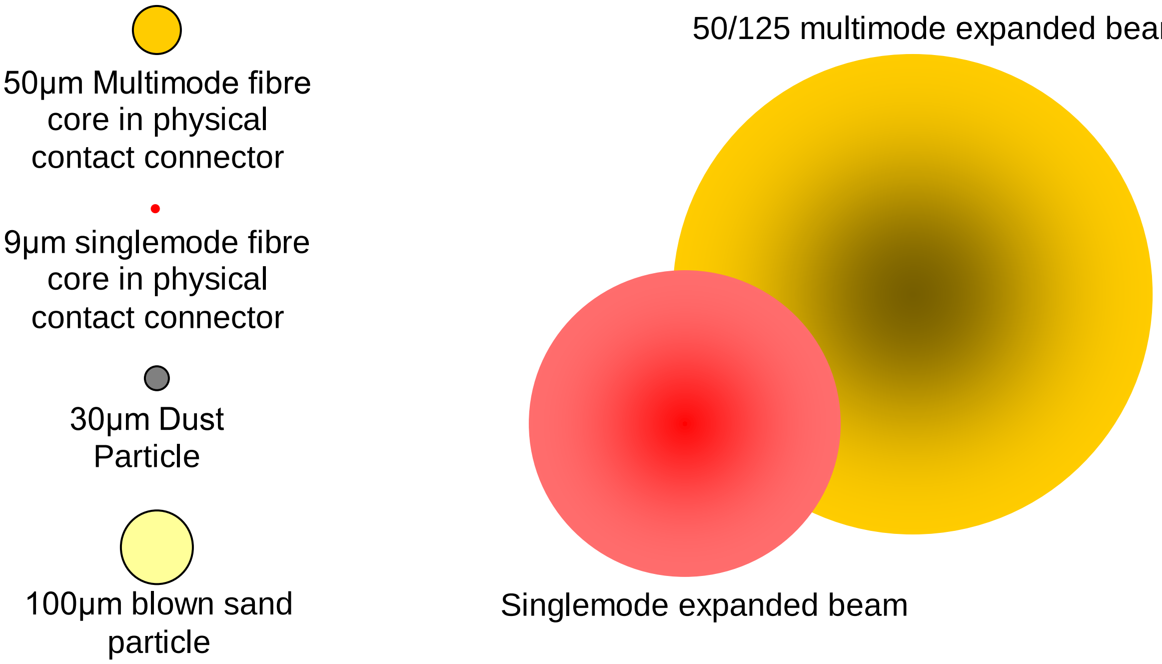
Expanded beam fibre optic connectors utilise a lens to expand and collimate the light emitting from an optical fibre. This collimated light beam is transmitted through an air gap to a mating connector, where the light is collected and focussed by a second lens into a second optical fibre to complete the connection.



With 50/125 multimode fibre, the expanded and collimated light beam has an active area of around 150 times larger than the original optical fibre core. In singlemode expanded beam connectors the active area of the light beam is approximately 2000 times larger.

The effect of collimating and greatly increasing the beam diameter means that the connector is less sensitive to small particles of dust or other contamination which could completely obscure transmission in physical contact type connectors.

The following diagram is a scale representation of physical contact and expanded beam diameters showing typical contaminant sizes:



The Expanded Beam Connector Insert

Multi-channel expanded beam connector inserts have been developed to offer a practical method of packaging the expanded beam technology. Typical expanded beam inserts comprise a stainless metal housing containing 1 to 16 spherical lenses (optical channels).

The Fibreco expanded beam insert utilises a unique, patented optical arrangement whereby the critical interface between the optical fibre and the lens is permanently sealed in a controlled atmosphere during manufacture. This ensures that no dust, moisture or other contaminants can migrate into the optical path during the product life.

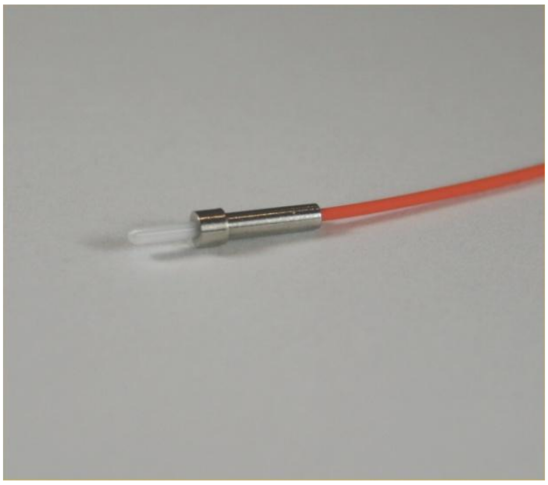
The front face of the expanded beam insert typically has a mating surface, an alignment pin and socket and one or more spherical lenses which are epoxy sealed. The lenses have an extremely hard anti-reflection coating. The Fibreco expanded beam insert has been carefully designed to avoid "dirt traps" and the largely flat front surfaces facilitate easy cleaning. Where ease of cleaning and low maintenance schedules are required, the addition of a window can be specified on some connector inserts to create a flush mating surface for swift and easy cleaning. Anti-reflection coatings are also applied to these windows to minimise back reflection.

The expanded beam insert is sprung loaded when assembled in a connector shell. When two connectors are mated, the expanded beam inserts are aligned by the pin and socket arrangement and contact under spring pressure on their mating faces. The spherical lenses or mating windows do not contact.

Fibreco expanded beam inserts are easily terminated with standard fibre optic termination tools and equipment. Termination is based on standard LC connector technology (Ø1.25mm) and is terminated onto optical fibre cable using the industry standard epoxy / polish technique. The termini are then simply inserted into the rear of the expanded beam insert and fixed in place with a retainer.

The termini can easily be removed from the expanded beam insert for connector re-use or repair. Importantly, should the expanded beam insert be damaged in service the connector can be repaired by replacing the expanded beam insert without the need for re-termination.

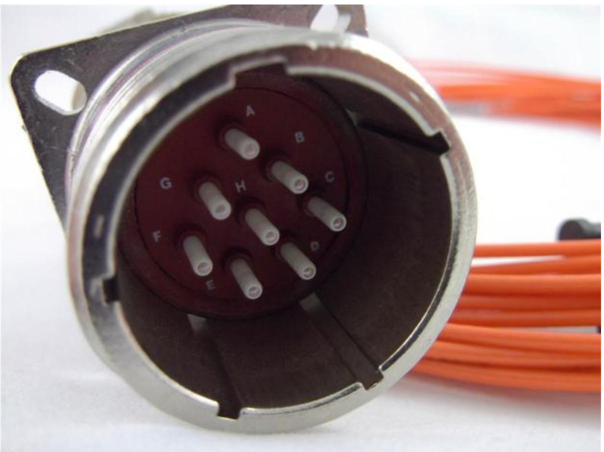
Fibreco Mini, Junior, Senior and Maxi Expanded Beam Inserts



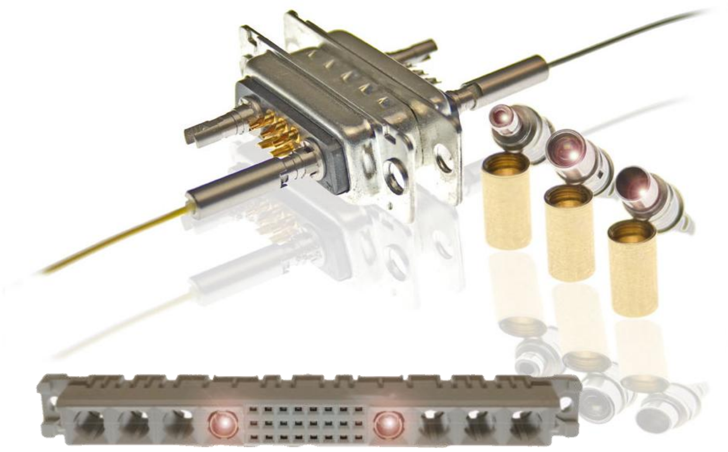
Fibreco Expanded Beam Termination Ferrule

The Expanded Beam Termini

In addition to complete inserts containing the expanded beam components, Cinch also provide through its GigaCom Interconnect EBOSA™ technology, the ability to provide individual expanded beam termini in popular form factors such as MIL-PRF-29504/4 and /5, and also ARINC 801 in both multimode and singlemode. EBOSA™ (expanded beam optical sub-assembly) provides all the expanded beam benefits highlighted in this document, but with the flexibility to integrate the termini into many more connector forms or custom designs. EBOSA™ also incorporates very easy termination and end face preparation by utilising standard LC ferrules on the prepared and terminated end. The EBOSA™ then simply screws together and is then inserted into the required connector.



EBOSA™ MIL-PRF-29504/4 style expanded beam termini in a MIL-DTL-38999 SIII connector (#16 cavities).



EBOSA™ termini in a D-sub DIN-41652 connector and DIN-41612 backplane connector.

Multi-channel Expanded Beam Connector Shells

Hermaphroditic type expanded beam connectors have been designed specifically for external harsh environment applications and are widely used in military tactical communications, outside broadcast, mining, offshore and many other industrial applications. Cable assemblies with hermaphroditic connectors can be easily daisy-chained and there is no requirement for male / female adaptors.

Connector shell materials to suit a wide range of environments are offered including aluminium alloy, stainless steel and nickel aluminium bronze.

Fibreco hermaphroditic tactical connectors are fully sealed (IP68 to 15 meters depth) mated or unmated and with or without dust-cap fitted.

The modular expanded beam insert design enables integration into many styles of harsh environment connector shell. Alternative connector types include MIL-DTL-38999 SIII derived and sub-sea connectors.

MIL-DTL-38999 SIII expanded beam connectors are used in electronic equipment interface applications on military vehicles, aircraft and ships.

Size 11, 13, 15 and 17 connector shells are offered with 1 to 16 optical channels.

The connector features the MIL-DTL-38999 SIII tri-start thread and one turn self-locking, anti-vibration coupling mechanism familiar to many military applications.

Dry-mate sub-sea connector with four channel expanded beam insert.

Stainless steel and silicon bronze shells with a depth rating of 3000 metres for ROV applications.

High Reliability in Extreme Environments

Whilst the connector shell design and the quality of the harness manufacture have an important bearing on the reliability of a harsh environment fibre optic connector, by far the most critical factor is its fundamental ability to withstand the harsh environment conditions both when the connector is mated (or with its protective cap fitted), and also in its un-mated and therefore un-protected state.

Physical contact connectors must also withstand the cleaning process as often damage can occur if untrained personnel attempt to clean the connector or incorrect cleaning materials are used. In contrast, expanded beam connectors do not require disassembly or any special tools or cleaning materials to properly clean the connector. Damage cannot occur from the cleaning process.

The following demonstrates the ability of the Cinch Fibreco Junior military tactical connector to resist mud immersion and be easily cleaned and returned to service with no detrimental effect on its optical performance:

1. Plug connector immersed in mud. The connector is fully sealed even without the dust cap fitted.

2. The mud will not cause damage to the insert. A physical contact connector would almost certainly already be destroyed in this state.

3. Initial cleaning to remove mud and debris from the connector face can be done by rinsing in water. A hose, bucket of water, stream or muddy puddle will do.

4. Connector end-face is clean after rinsing.

5. The insert face is dried and wiped clean. Ideally a clean cloth or tissue is used but if these are not available the bottom of your coat will suffice. No damage to the insert surfaces or lenses will occur.

6. Connectors plugged and ready for service.

The whole cleaning cycle was completed in under 5 minutes. Insertion loss was measured between -0.90dB to -1.15dB (9/125, 4 channels) with an optical time domain reflectometer.

Conclusion

Whilst physical contact connectors have lower insertion loss than expanded beam connectors when the product is in perfect condition, their optical performance will constantly degrade over the product life eventually leading to signal failure.

Regular maintenance of physical contact connectors is required to maintain good optical performance. This can involve disassembling the female connector parts, removing alignment sleeves (small parts which are easily lost in field conditions) and the use of special cleaning swabs, solvents and tools (including an end-face inspection microscope).

The servicing of physical contact connectors can only be performed by specially trained technicians. If the termini have been damaged, cleaning will not restore original optical performance. Damaged termini end-faces will require re-polishing and although this can be achieved in the field, it is preferred to carry this out a fibre optic polishing machine in workshop conditions. Connectors with severely damaged termini will require complete re-termination or replacement.

Expanded beam connectors have been shown to withstand extreme environments without the need for special servicing or cleaning equipment. Protecting the optical fibres behind lenses ensures that no damage or degradation can occur.

The non-contact design of the optical surfaces in expanded beam connectors results in higher insertion loss than physical contact connectors (multimode typically -0.7dB, singlemode typically -1.0dB). However, the optical performance of expanded beam connectors is constant throughout the product life and the likelihood of product failure at a critical point is greatly reduced.

Edited: Michael O'Farrell
Global Fibre Optic Product Manager
Cinch Connectors