

Fiber Optic Expanded Beam Size 16 Termini

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ABSTRACT

For most data and telecom fiber optic applications the physical contact (PC) concept is preferred for all indoor and even some outdoor applications. But when these connectors are subjected to a harsh environment, the performance of standard PC connectors has proven unreliable in many applications due to their sensitivity to contamination. The subject for this paper is the design of a small form factor expanded beam (EB) fiber optic contact pair suited for operation in a challenging environment. The contacts conform to the dimensional envelope of MIL-PRF-29504/4/5D and employ a separable lens unit design which provides the option for field-installable terminations. The EB concept typically exhibits a higher loss than the PC connection, but preliminary results of the new design indicate that the size 16 termini pair using 1.25mm lenses and ferrules yields a very good loss performance.

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INTRODUCTION

With advantages such as superior bandwidth capability, reduced weight, EMI immunity and high density, fiber optics is becoming more attractive both as a replacement for copper and as a hybrid solution. The demand for reliable transfer of high data rates are increasing the implementation of fiber optics in applications which formerly were reserved for copper contacts. The question is if the fiber optics is rugged enough to survive the often harsh conditions experienced in aviation, military and marine applications. The MIL-PRF-29504A specification for fiber optic physical contact termini designed for the MIL-DTL-38999L style contact cavities was one of the first standardizations of fiber optics used in a harsh environment. Today, more than 20 years later, there are still issues which challenge the reliability of the sensitive fiber interface when operating in a harsh environment.

CONNECTOR TYPES

Physical Contact Connectors

These optical connector types were primarily designed for indoor applications in controlled environments, such as data and telecom. But when it comes to contaminated and rugged uncontrolled environments, the PC concept often performs poorly and is prone to suffer irreversible degradation for various reasons. The fact that sensitive optics is exposed when connectors are un-mated opens the possibility for

contamination of the optical pathway by the many particulates present in the harsh environment. Contamination of the pristine polished fiber end face by dust and other damaging particles can be detrimental to a system. Once an interface is separated for any reason, cleaning is required before any re-assembly is done. The fiber and the ferrule end-face, including the inside of the alignment sleeves, requires careful cleaning using special cleaning agents and use of a specific procedures. If the operator is not adequately trained, an improper cleaning process can actually add more contaminants to the fiber than what is being removed. If a small particle is caught at the interface between the spring-loaded fibers, it will initially block part of the light and introduce optical loss. If the application involves vibration, an abrasive particle may get imbedded into the glass surface and cause permanent damage. Likewise, if the connection is in an environment requiring multiple separations, optical degradation will occur sooner rather than later due to wear of the fiber surface. In addition, a field inspection microscope is required in order to assure sufficient cleanliness before assembly along with necessary means to keep the consumables contamination free. A desirable option to the PC terminus is to use a fiber optic design which is less sensitive to these failure modes and provides a dedicated design for use in rugged environments. One such solution is an expanded beam connection.

Expanded Beam Connectors

The EB concept includes an expansion/contraction of the beam between the emitting and receiving fibers enabled via lenses positioned near or at the respective fiber end faces. An air gap exists at the interface between the lenses ([Figure 1](#)), thus; there is no physical contact between any of the sensitive optical elements during operation.

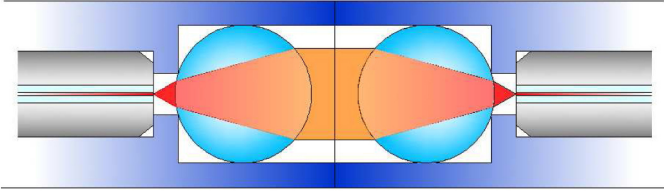


Figure 1. Expanded beam concept

Furthermore, because the ferrule end face is enclosed behind the lens, the fiber will never require cleaning. Only the exposed outer lens surface may be contaminated, but the optical performance is easily restored by a simple cleaning procedure. Because the beam size is substantially expanded when traversing the mechanical interface, the signal will not deteriorate by the presence of the same airborne contamination particles which seriously affect the performance of the PC connection. The effect of dust and contaminants has been strongly reduced with the introduction of the EB design.

The lens on the launch side, typically a spherical ball lens, is used to expand and collimate the beam emitted from the launch fiber. The expanded beam remains collimated across the mechanical interface until it reaches the receiving lens, a similar sized spherical ball lens, which focuses the beam onto the end face of the receiving fiber. As an example of commercially available EB connectors, [Figure 2](#) shows two sizes of a 4-channel EB inserts mounted in a 38999 circular style connector plug. The hermaphroditic EB insert design uses a pin/hole mechanism for alignment during mating. [Figure 3](#) depicts another EB connector type which here is shown with rearward removable size 8 EB pin and socket termini mounted in 38999 shells [[1](#)].



Figure 2. Two sizes of 4-channel EB inserts in MIL-38999 shells



Figure 3. Two single channel size 8 AWG EB termini in MIL-38999 shells

As an example of beam expansion, consider a 62.5/125 micron multi mode fiber behind a 3mm diameter ball lens. The expansion factor is 14, which means that the cross sectional beam area becomes 208 times larger than the area of the emitted beam from the 62.5 micron fiber core.

A more detailed comparison between the PC versus EB concepts can be found elsewhere [[2](#)].

Size 16 Expanded Beam Pin and Socket Termini

In order to further miniaturize the EB size 8 (shown in [Figure 3](#)) and to maintain the same small form factor envelope as defined in the MIL-29504 standard, multimode expanded beam pin and socket contacts have been designed using standard components such as a 1.25mm diameter ferrule and a 1.25mm spherical ball lens ([Figure 4](#)).

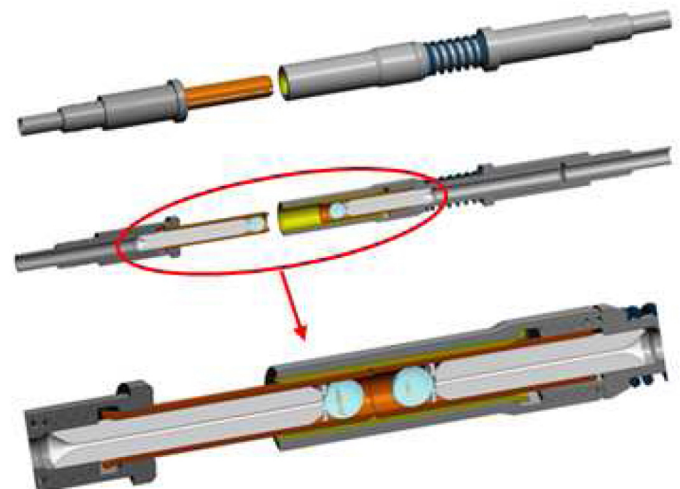


Figure 4. Size 16 pin (left) and socket (right) shown in unmated and in mated condition

The design takes advantage of the excellent mechanical alignment accuracy obtained by mount of the same size ferrule and ball lens within a precision alignment sleeve. This is done on both the pin and the socket termini. The socket side further has a mating sleeve which telescopically receives and aligns the two termini when the 38999 connector plug and receptacle are mated. The proper distance between the fiber and the lens (the lens back focal length) is maintained by use of a 'doughnut' shaped spacer disc.

One major advantage of the design is the option for field termination. As shown on [Figure 5](#), both the pin and socket termini can be separated from their lens units. This allows termination to the fibers and fiber polish in field. Once the polish is complete, the lens units can be mounted. This added freedom allows the user choose the length of the fiber cable in the last minute or to re-terminate the cable if needed. A further advantage is that the individual lens units can be changed without disturbing the cable assembly mount or cable routing.

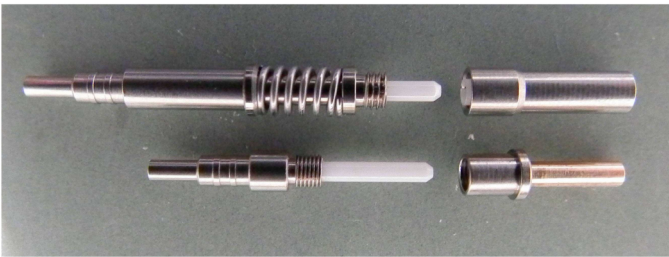


Figure 5. Size 16 socket & pin field installable termini with separated lens units

LOSS MECHANISMS

Due to the one-to-one confocal EB lens system, the correlation between the optical loss and the mechanical tolerances/offsets is similar to that in effect for a PC connection. But while fairly accurate formulas exist for a single-mode system there are only a limited number of formulas derived for the multi-mode system and it is therefore often preferred to predict the MM performance by use of optical modeling software.

The performance of the EB system is governed by the three most common mechanical loss mechanisms: transverse offset, longitudinal offset and angular tilt.

The three mechanisms apply independently, to both the fiber position and to the termini halves, but with different weights. Losses due to Fresnel reflections are another contributing loss factor which occurs when a refractive index mismatch exists at an optical interface. For several interfaces their combined effect defines a minimum loss threshold for the interconnection. This loss contribution can largely be compensated for by applying anti-reflection coatings to the optical surfaces. Finally, spherical lens aberration is also a contributor. As mentioned earlier for the EB design, no

contact exists between the optical elements, therefore performance deterioration due to vibration is eliminated. Another valued advantage of the EB system is that the loss distribution has a narrow standard deviation due to the stable and repeatable performance over the life of the interconnection.

MODELING RESULTS

Modeling shows ([Table 1](#)) that for a 1.25 mm lens system using a 50/125 micron fiber at 850 nm wavelength, the beam expansion is 270 microns, a factor of 5.4. This means, after exit from the launch fiber, the beam cross sectional area is expanded 29 times at the optical interface. The optimum position for the fiber end face is at the back focal length of the lens which is 72 microns off the lens surface. This means that we need to introduce a spacer which will maintain this distance between the fiber end face and the lens surface. The reflection loss for the system is modeled to be 0.356 dB. This number defines the lowest loss achievable for the current EB system at perfect alignment. Since the lenses are AR-coated to less than 0.5% reflection their contribution can be ignored. The reflection loss can therefore be attributed to the uncoated end faces of the source and receiving fibers. If desired, the fiber end faces can also be AR-coated which will reduce the minimum loss level substantially, but it will add to the cost.

Table 1. Modeling results for a 50/125 micron fiber with a 1.25mm ball lens at 850nm

Lens Diam [mm]	Fiber size [um]	Wavelength [nm]	Lens Back Focal Length [mm]	EB Expansion D [mm]	Expansion Factor	Reflection loss [dB]
1.25	50/125	850	0.072	0.270	5.4	0.356

Transverse Offset

There are two types of transverse offset that can add loss to the system. The effect of the first, and the larger contributor of the two, is shown in [Figure 6](#). The graph shows that the loss performance is very sensitive to fiber transverse offset relative to the optical axis through the lens. This is probably one of the most difficult variables to control in the EB system. For a 50 microns fiber core, a 3 microns transverse offset will add 0.45 dB to the connection loss. For this reason, the design objective for the transverse fiber offset is specified to be maximum ± 3 microns.

The second contributor is the transverse offset of the termini. The graph of [Figure 7](#) shows the effect of transverse offset between the pin and socket. Here, due to the system beam expansion factor of 5.4, the sensitivity is reduced, and adding a 0.45dB loss will require a 16.2 microns offset between the mated connector halves. For the size 16 EB design, such a large transverse offset of the termini is not possible due to the snug fit to the alignment sleeve during mating.