Expanded Beam Termini

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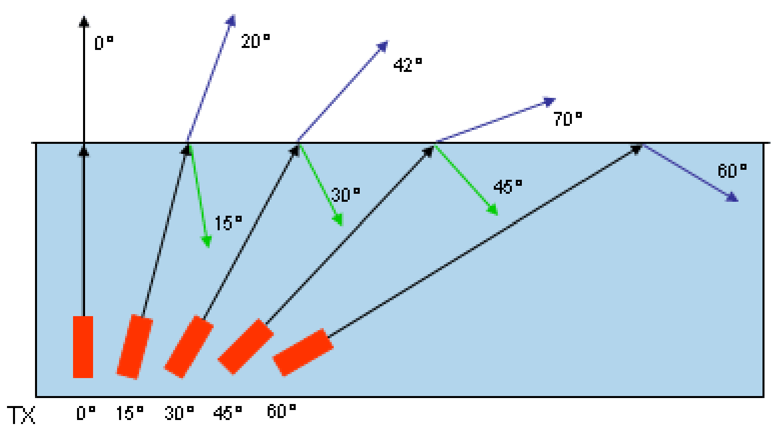
Abstract:

Fiber optics has many advantages in communication when compared to its predecessor, copper, but ease of termination and connection is not one of them. Aligning a 9 micron fiber core is difficult enough, but today's use of fiber in harsh environments is presenting new challenges in engineering. Connecting fibers in high-vibration applications is especially problematic. Most conventional techniques for connection two fiber cables employed biconical or cylindrical butt-coupled ferrules to hold and align the fibers. These connections are vulnerable to contamination and scratches, so new methods such as Expanded Beam were invented to try to make fiber connection easier.

Expanded Beam termini use existing ceramic ferrule connectors with a ball lens attachment. The lens expands and collimates the beam from one termini to the next, which also has a ball lens. The second lens focuses the light onto the fiber core for transmission through the cable. The expanded beam is much more resistant to dirt and scratches, giving it over twice the lifetime of conventional connectors. We are qualifying these new termini and connectors for Insertion Loss and Reflectance, as well as thermal and vibrational sensitivity, to determine if Expanded Beam is a viable product for our company.

The basic principles of the optical fiber are very simple, and result from Snell's Law. To begin, the optical fiber is made of two types of glass: the core and the cladding. The two glasses have slightly different indexes of refraction, because the core is doped with elements like Germanium. When constructed in a cylindrical fiber, the core is the inner cylinder and the cladding surrounds it. This creates an interface between core and cladding, and as I will show, this interface guides the light down the fiber with little loss.

We know from Snell's law that light is refracted at an interface. From this, we can see beyond a particular angle of incidence, all the light will be reflected from the interface. This phenomenon is known as Total Internal Reflection:

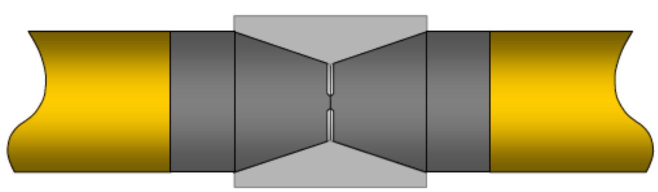


Notice that, as the angle of incidence from glass to air increases to 60°, all the light is reflected back into the glass. This principle is behind the fiber: since the core is of higher index than the cladding, and the properties of both are correctly adjusted, all the light is reflected inside the core and travels down the fiber (of course, some losses occur due to Rayleigh scattering).

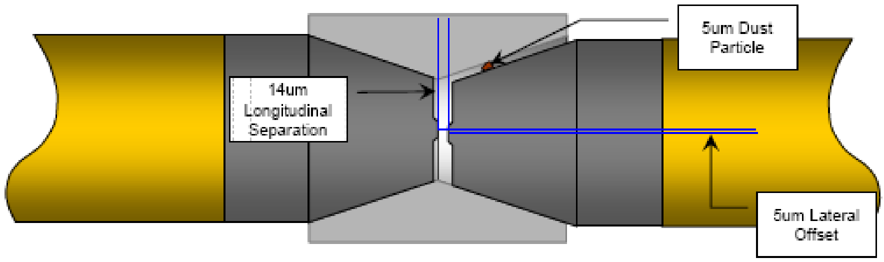
There are two different types of optical fiber: single mode (SM) and multi-mode (MM). Simply put, a 'mode' in the fiber is a particular ray. Therefore, in a single mode fiber there is only one mode, or ray, in which the light can travel. In multi-mode fiber, many modes are possible. To achieve fibers that allow only one mode we use a small core size like 9 µm. Single mode fibers do not show modal dispersion, which occurs because modes in a MM fiber travel at different speeds. Therefore, single mode fiber is used for long distance communication and high precision applications.

Now, with that brief overview of the function of a fiber, we must jump into manufacturing issues that arise in fiber optic termination. The core and cladding are all that is needed to guide light in a fiber, but much more is necessary to produce usable cables. First, when optic fiber is produced it instantly is coated with a plastic (Acrylate) coating to 250 µm to protect it during handling and cable manufacturing. After the acrylate, a tight PVC buffer is applied to the fiber. Aramid yarn (Kevlar) then surrounds the PVC buffer, and an outer jacket is applied to cable to hold everything in place. Keep in mind that this is the simplest single fiber cable; cables containing over 1000 fibers exist with complicated, watertight constructions.

Now, termination of these cables is not easy. Ceramic or steel ferrules are used to hold the unprotected fibers, and the ends of both ferrule and fiber are polished smooth. The Kevlar is used to hold the connector to the cable, so that stress is never applied to the fragile fiber. As previously mentioned, original termini used biconical butt-coupling to connect two fibers (see picture).

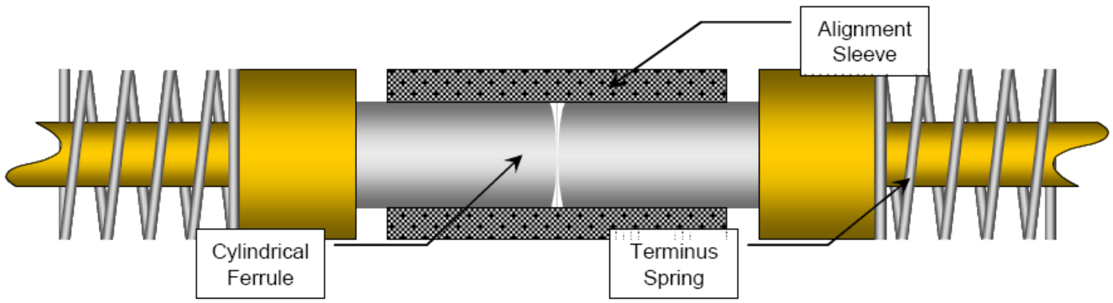


Alignment was provided by the conic section of the ferrule, and the two ferrules were **not** intended to come into physical contact. Early connectors such as TFOCA 1 employed this method. Biconical connections have generally gone by the wayside of late, due to alignment issues caused by small amounts of dirt or debris:

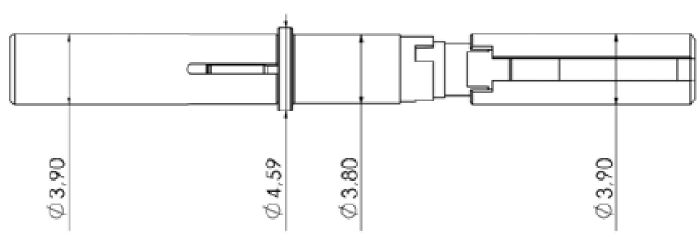


This type of lateral offset must be avoided at all costs, particularly in SM applications. A 14 µm separation means a lot for a 9 µm core size, so cleanliness was a major problem for these connectors, bringing on the cylindrical Physical Contact connectors of today.

Cylindrical Physical Contact connectors are dome-polished ceramic or steel cylinders that are spring loaded to ensure physical contact at all times. Popular connectors of today, including FC, LC, SC, ST, SMA and most military termini, including the M29504, employ physical contact. These are difficult to manufacture, as strict geometrical requirements must be met and scratches or dirty cores can interrupt or disable communications. Current loss values for our connectors run around 0.35 dB Insertion Loss and -55dB Reflectance for MM, -65dB for SM and -75dB for SM angled-polish. The angled polish improves back-reflection values because reflected light is sent off-axis, usually at around 8°. The following diagram shows important features of cylindrical butt-coupled connectors (note the dome polish and physical contact):



Now, finally to Expanded Beam connectors. The Expanded Beam termini use similar ferrules with small ball lens attachments to alternately focus and collimate the light between termini. The ball lenses are designed specifically for the termini, with particular spot sizes and focal lengths for their applications. Our company is mostly interested in the M29504 Expanded Beam termini for military customers. Below is a graphic of expanded beam connection with a schematic and picture of a M29504 EB termini:



On each termini lies the ball lens, which takes the light exiting the fiber and collimates it into a beam on the order of millimeters. This beam is the picked up easily by another ball lens that focuses the light that strikes it onto the core of the fiber.

The only important advantage to these termini is their ability to withstand contamination and damage simply due to the use of the expanded beam. For example, a tiny 80 μm fleck of dust could cover most fiber cores and stop the cable from functioning, but this same 80 μm bit of dust would not block nearly as much light from a millimeter-size beam. This is the advantage of expanded beam, especially in military applications such as shipboard or aerospace cabling.

Unfortunately, since my company is in early stages of testing EBOSA (Expanded Beam Optical Sub Assembly) M29504 termini I cannot discuss many of my testing results. However, I will mention some things we are looking for and some published results of others. First, a common concern using M29504 termini in high-channel 38999 shells (38999 is a military connector back shell, samples will be provided) is that the keyway has a small amount of mechanical play that leads to increased Insertion Loss in high-vibration locations like Humvee's and aircraft. As the military shell turns, the termini rotate with respect to one another and light is lost. We are assembling 29 channel

38999 cans with EBOSA termini and rattling them around to watch the Insertion Loss values and determine if EBOSA out-performs current connectors on that test.

One advertised advantage of the EBOSA termini is mating durability. A company selling EBOSA termini states that they achieve over 5000 mates while current technology gets only 2000. We have not yet verified this data, but it makes sense that EBOSA are more resilient to mating problems because of the large spot size.

The other advantage comes in lateral misalignment. This is very similar to EBOSA's dust resistance: if the termini are misaligned laterally by 10 µm, the comparatively huge spot size of EBOSA will provide far less loss than cylindrical butt-couple. Gigacom, a Swedish company that produces M29504 EBOSA, claims only 2dB loss at lateral misalignments of 100 µm! That would cause 40 or 50dB of loss in a conventional connector.

Expanded beam and ball lens technology seems to be taking a hold in particular markets in fiber today. It's resistance to dirt and contamination makes it attractive for high-end applications, and low sensitivity to misalignment makes it a great harsh environment candidate. Unfortunately our company did not move as fast as I would have liked on producing this technology, as things in the business world often go, but I was able to learn a great deal about fiber optic connection history and development. It is important to understand the innovations that brought us to our current technological location to be able to adapt to and predict the future. As fiber assumes a larger role in our technology, huge developments in connection technologies will certainly be required, and EBOSA is an important step in that development.

Sources:

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