Selecting a Small-Form-Factor Fiber Optic Connector for Private Networks

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Consider the future when making the choice

Introduction

In just the last few years the Internet, and its close cousin, the Intranet, have had a major effect on private network data communications. The mix and volume of data and voice traffic being carried on these networks is changing rapidly, with more applications and larger data files than ever before. To accommodate this increased traffic, private networks are increasingly being built with fiber optics.

Increased use of fiber optics results in more electronics, cable, and apparatus being installed into smaller and smaller physical spaces. Hence, a primary focus of many development efforts is on the fiber optic connector; the small passive device that connects the fiber optic cable to the optoelectronics driving these networks. These new connectors are known as “Small-Form-Factor” (SFF) connectors. Many are designed to double the density and hence the physical capacity of LAN optoelectronics and patch panels. They are also designed to be installed more easily in the field.

While reduced connector size is a desirable objective, not all SFF connectors are the same. There are significant differences that may seriously restrict their use in current and future applications.

The criteria for selecting a SFF fiber optic connector may be divided into three categories: (1) connector design considerations; (2) system considerations; and (3) business considerations. It is important to look beyond the advertising jargon that might focus on a manufacturer’s main theme, such as extremely low cost (a design consideration) and concentrate on far more important issues such as channel performance (a system consideration) or system licensing (a business consideration). The purpose of this article is to examine the important factors involved in selecting a new fiber optic connector that will cost-effectively meet not only today’s requirements, but also those that are likely to arise in the not-too-distant future.

Connector Design Considerations

What's really important?

True, Space-saving Design

A primary feature of all SFF fiber optic connectors is reduced size. SFF fiber optic connectors are approximately one-half the size of traditional connectors, such as the ST®[1] and SC. Small size is important because, as more fiber is being used in private networks, more electronics are being squeezed into less space. With older connectors, electronics manufacturers could not achieve port densities equivalent to copper on switches, hubs, and routers; now high density is possible. SFF connectors also make smaller fiber network interface cards (NICs) practical for computer workstations and servers. SFF connectors are highly recommended for any installation where space is a consideration.

Fiber Alignment

Since the introduction of fiber optic connectors in the 1970s, there have been many different methods of retaining the fiber in the precise alignment necessary to insure minimum light loss and to minimize reflections between joined sections of cable. Cylindrical ferrules, 2.5 mm in diameter, were the most popular alignment mechanism. Some new connectors use 1.25 mm diameter ceramic or glass ferrules, which reduce not only cost but also installation polishing time. Another new SFF connector utilizes an open plastic V-groove in which two fiber ends are held in compression via a permanent bend in one of the fibers in the groove. Yet another design utilizes closely spaced metal ferrule alignment pins.

Although all of these designs are viable, some industry analysts are skeptical about the long-term reliability of the plastic, open-V-groove-based connector. Others are concerned about fiber cleaning in connectors with closely spaced metal pins where debris might collect and about cleaning connectors with exposed fiber. Traditional ferrule-based connectors have proven themselves over many years of use to offer extremely high reliability and easy cleaning.

Connector performance is directly related to the precision of the fiber alignment. A comparison of published performance figures for major SFF connectors shows significantly better performance with the small 1.25 mm ceramic ferrule-based connectors than with other SFF designs.

Fiber Spacing

Though most of the new connectors are approximately the same size externally, several of them place the fibers as close as 750 µm in internal proximity. Close fiber spacing was developed for use with use with ribbon-based cable rather than discrete fiber cable. According to several optoelectronic device manufacturers, close fiber spacing can make it more difficult to optically and electrically isolate the two transmission paths, resulting in higher optoelectronics costs for connectors utilizing this design.

Close fiber spacing can also complicate mounting the connector to widely used building cable, containing buffered fibers with an outside diameter of 900 µm. When this cable and these connectors are used together, fibers are squeezed together to conform to the 750 µm fiber spacing in the connector. Squeezing the fibers together can lead to higher loss and/or premature failure of the fibers. Selecting connectors with greater fiber spacing, as great as 6.25 mm from the available SFF choices, can help to alleviate loss and failure concerns.

Intuitive Operation Similar to RJ-45

When Bell Laboratories invented the RJ-11, the first modular connector for copper cable, in the late 1970's, the designers probably never envisioned the tremendous popularity it would achieve. The compact size, low cost, and intuitive operation of these connectors was so attractive that it was used in many successive generations of new modular connectors and culminated in the almost universal RJ-45 8-pin modular connector used today for most copper private network connections.

Some of today's SFF fiber optic connectors emulate not only the size, but also the intuitive operation of the RJ-45. For example, some are polarized which insures that the transmit and receive fibers are always correctly oriented. Connector polarization is required in various standards including TIA 568-A (Commercial Building Telecommunication Cabling Standard) and ISO 11801 (the international equivalent). Some SFF connectors also offer visual verification of proper polarity through the use of A/B markings on the adapter into which the connector is inserted. Audible clicks are another reassuring feature that some SFF connectors have adapted from the RJ-45. Color-coding can help users quickly distinguish multimode (beige) and single-mode (blue) connectors. A system designer should use a SFF connector that offers both physical and visual polarization, color-coding, and an audible click to verify full insertion.

Other Convenience Features

With more connectors occupying less space, it is easy for fiber optic cordage to get snagged, especially while the connectors are being unplugged. A few SFF fiber connectors offer an anti-snag feature that prevents snagging from occurring. Connectors designed to prevent snagging can reduce time and expense in installing and maintaining fiber networks.

Easy Field Mounting

It is often impractical to specify exact lengths for pre-connectorized cables in private network applications. Because cables are usually in or behind walls and may take many turns, accurate measurements may be very difficult. The connectors on factory-terminated cables may also be damaged or pulled off while the cables are being pulled during installation; for that reason field mounting of fiber optic connectors in private networks is usually necessary. Field-installable connectors are available using a variety of technologies. One method is to use fiber stubs, which essentially "splice" the cable to a short length of fiber in the rear of the connector. Some field-mountable connectors employ anaerobic adhesives, requiring no heating ovens to cure the adhesive that bonds the fiber to the connector ferrule. Other field-mountable connectors employ heat-cured epoxies.

While installation of fiber stub connectors is very fast, these connectors tend to be quite expensive and add the loss associated with the fiber-stub splice. Adhesive-based connectors are less expensive, but more field labor is required to install them. The decision as to which field mounting method to employ should be based on connector costs, short-term and long-term performance requirements, local labor costs, and the skill of the labor force.

Many installers prefer adhesive-based, field-mountable connectors because they are already familiar with them and no additional training is required. They may already have most, if not all, of the required installation tools. Other installers prefer fiber-stub connectors because labor costs are an issue, and installation time is critical. In these days of shrinking insertion loss budgets (as low as 2.5 dB for Gigabit Ethernet), a system designer must weigh the convenience of a fiber-stub connector against the additional loss incurred from the extra connection (splice) introduced with these connectors. The designer should also beware of SFF connectors that are not field-mountable; these may require special fiber or cordage that may not be readily available from alternate sources.

Adaptability to Existing Test Equipment

Another limitation of some SFF designs is the difficulty of adapting them to test equipment, most of which is currently designed to accept 2.5 mm ferrule-based connectors such as the ST, SC, and FC. Relatively inexpensive adapters are available for 1.25 mm ferrule-based SFF connectors that may be easily interfaced to existing test equipment.

Single-fiber vs. Multiple Fiber Connectors

Some of the new SFF connectors are duplex designs in which both fibers are installed in one physical connector. While this approach may reduce the number of parts in the connector assembly, it can make precise fiber alignment more difficult. Achieving ideal alignment is inherently more difficult with two fibers in a single ferrule than with a single-fiber in each of two single-fiber connectors yoked together. The result of sub-optimal fiber alignment is increased insertion loss and/or reflections.

Holding two single-fiber connectors together in a yoke adds additional freedom for each connector to move freely and mate more accurately, much as the independent rear suspension of an automobile allows each wheel to more closely track the road surface. The true test of connector design is in single-mode, and the best-performing single-mode designs are all single-fiber or ganged single-fiber connectors. A system designer should compare both single-mode and multimode insertion loss specifications for all SFF connectors, and it will be obvious that the highest performance connectors employ single-fiber connectors arranged in duplex form.

Not all private network applications require exactly two fibers, but most SFF connectors are designed to accommodate only two. Some video applications such as security and video distribution may need only a single-fiber. Single-fiber, SFF connectors provide application flexibility, allowing yoking in two-fiber applications or single use where required. Separate connectors also eliminate the need to cut off and re-terminate connectors to correct polarity problems. Separate connectors may simply be unplugged and re-inserted with the correct polarity reducing both waste and cost.

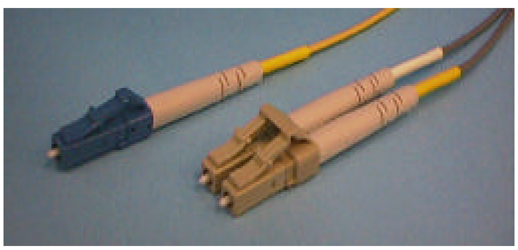

Figure 1

Single-fiber & Duplex LC Connector Configurations

Insertion & Return Loss Critical

System speeds continually increase, and increased speeds usually result in lower loss budgets. The lower the insertion loss of the SFF connector, the longer its useful life in private network systems. Low loss is important because it allows more connections and/or longer links, increasing the options for network designers as compared to other higher-loss SFF connectors. Low-loss connectors may also reduce optoelectronic drive current requirements, leading to longer device life. The advertised loss of some SFF connectors offered today can be up to 0.5 dB (typical), whereas others have loss as low as 0.1 dB (mean).

Statistically-based performance is specified for some SFF connectors and is the only reliable measurement parameter. SFF connectors are available today with extremely low insertion loss, as low as 0.1 dB ("µ" or statistical mean) for both single-mode and multimode versions. This high level of performance is possible if the connector is manufactured with its critical parts, such as ferrules, made of high precision materials designed to very tight tolerances. When looking at loss figures, it is important to verify that a manufacturer's advertised level of performance can be attained using field termination tools and methods.

Some of the highest-speed data applications, as well as analog video systems, are especially sensitive to signal reflections back into the transmitter. "Return loss" or "reflectance" is the ratio of the reflected power to the forward power, and the higher the number, the better. Connector return loss is an important parameter to examine when selecting SFF connectors used in these high speed applications since return loss is affected by connector design, manufacturing tolerance, and installation techniques. It is possible to select a SFF connector with a minimum 55 dB single-mode return loss and average 33 dB for multimode return loss, but most small connectors do not offer this level of performance.

Compatibility with Standard Fiber

Some manufacturers of SFF fiber connectors "recommend" the use of proprietary fiber in their jumper cords. Special fiber may be required because of some special characteristic of the connector itself; for example, the design may hold fibers in a small-radius permanent bend. Such bends are detrimental to fiber life so special strengthened fiber is needed to compensate for the added stress. Selecting a connector that does not require special fiber may be the most reliable as well as the most practical choice over the long run. Similarly, jumpers requiring proprietary fiber cordage may reduce the number of supply sources.

Multimode & Single-mode Support

Today's private network fiber needs are predominantly met using multimode fiber optic cable and apparatus. Until now the speeds and distances required have easily been met in most applications with 62.5 μm multimode fiber. As we enter the era of gigabit private networks, however, network designers are beginning to install single-mode fiber for some of the highest-speed and longest-distance applications, and to support broadband analog video. In some cases, single-mode fiber is being connected to active backbone optoelectronics for immediate service; in other cases, it is being installed in parallel with multimode fiber and being left "dark" for future use. Clearly single-mode fiber is becoming more important in private networks, and its use will undoubtedly increase greatly in the future.

Single-mode applications increase the performance demands on connectors, so it is prudent to select a new fiber optic connector that has proven itself in single-mode as well as multimode applications. While radically new connector technologies, such as those eliminating the traditional ferrule, may be attractive for low-cost multimode systems, it is very difficult, if not impossible, to apply these designs to single-mode connectors. For example ferrule-less single-mode connectors may be impractical, due to the high precision alignment required for acceptable single-mode performance. Since a connector decision made today greatly affects network capability in the future, forward-looking network designers are wise to look for a SFF connector that is currently *shipping* (truly available) in both single-mode and multimode versions.

System Considerations

The fiber optic connector as a component of a complete system

Channel Performance

Until recently, connector loss was of more concern in single-mode public network applications which are designed to operate at very long distances and close to the limits of the link power budget. Private network power budgets for 10 Mbps Ethernet and 100 Mbps Fast Ethernet have traditionally been more than ample (in the range of 10-12 dB) for the limited distances and lower speeds of typical fiber optic links. With the advent of gigabit-per-second applications such as Gigabit Ethernet and 2.5 Gbps ATM, for example, power budgets have become far smaller than those available for older Ethernet, Fast Ethernet, and FDDI applications. Power budgets available to overcome insertion loss in Gigabit Ethernet are only 2.5 dB for 62.5 μm multimode fiber over the entire passive fiber optic link. This means that the performance of the entire fiber optic link (or channel) is now of critical importance to the private network designer.

As stated previously, SFF connector insertion loss may vary considerably, depending on design. Obviously, connectors contribute to the performance of the channel, but there is more to channel performance than the connector alone. If a manufacturer simply says "our cable and connector meet the requirements of TIA 568A," a system designer should investigate further. Meeting TIA 568-A does *not* insure that any link or the system will work.

Fiber optic cables are specified in terms of loss and bandwidth, and *both* affect the power budget. TIA 568-A specifies that premises cables have a maximum loss of 3.75 dB/km and minimum bandwidth of 160 MHz-km at 850 nm, though some companies offer standard cable products with maximum loss of 3.4 dB/km and minimum bandwidth of 200 MHz-km. Connectors are specified with various insertion losses in different building cabling standards, such as 568-A and IS11801. "Typical" or "average" insertion losses of 0.5 dB and maximums as high as 0.75 dB may meet these standards, but may also be inadequate for operation with Gigabit Ethernet, as shown later in this article.

Fiber optic systems allow extended distance operation compared to copper systems operating at the same speed. Several years ago the TIA issued TSB-72, "Centralized Fiber Optic Cabling Guidelines," detailing how to design fiber-to-the-desktop systems in which LAN electronics are centralized, rather than distributed in telecommunications closets. Centralization using fiber optics can lead to significant cost savings over the lifetime of horizontal cabling systems due to fewer idle ports and reduced outages, as well as reduced administrative and maintenance expenses. The maximum fiber link distance specified in TSB-72 is 300 meters.

Designing a 300 meter link to support the 2.5 dB Gigabit Ethernet cable plant loss budget demonstrates the importance of selecting low-loss connectors and fiber optic cable. Well-specified connectors provide an average or mean insertion loss (μ) and provide a standard deviation (σ) that takes into account statistical distribution about that mean. Some manufacturers specify only a "typical" loss, which may not represent the average and provides no information about the variation from connection to connection. A mean and standard deviation are often required to determine whether a link will work, for a given level of confidence.

A "2σ" statistical analysis can be used to determine the expected channel insertion loss with a confidence factor of 98%. The difference between the 2.5 dB Gigabit Ethernet link *insertion* loss budget and the *channel* insertion loss is the loss "margin" or safety factor. For example, if the channel insertion loss is 1.8 dB, the available loss margin is 0.7 dB (2.5 - 1.8 = 0.7). Channel insertion loss for a 300 meter link may be calculated with the following equation:

$$\textbf{Channel Insertion Loss} = \textbf{Loss}_{\textbf{300m cable}} + \mathbf{n}_{\textbf{conn}}(m_{\textbf{conn}}) + 2\sqrt{(s_{\textbf{conn}})^2 n_{\textbf{conn}}}$$

Where: $\mathbf{Loss}_{300m\ cable}$ is the maximum 300 m cable loss

m_{conn} is the mean connector loss

n_{conn} is the number of connections in the link

s_{conn} is the standard deviation of the connector loss

A network designer may consider a link consisting of low-cost components, with three 0.5 dB connections and standard 3.75 dB/km cable. The standard deviation for such a connector is conservatively estimated at 0.2 dB. Using the above equation, the channel insertion loss will be 3.3 dB, exceeding the Gigabit Ethernet budget by a considerable amount and possibly leading to failure of the link (see Table 1, "Industry Low Cost Channel"). Substituting "better" connectors with a loss of only 0.2 dB, with a standard deviation of 0.25 dB, and standard cable, will result in a channel insertion loss of 2.6 dB. A channel insertion loss of 2.6 dB also exceeds the Gigabit Ethernet 300 meter link budget (Table 1, "Industry Average Channel").

Option ↓	Number of Connections* →	2	3	4	5	6
OptiSPEED™ LC Channel (a) loss/connection (μ_{conn}): 0.1 (b) loss/connection (σ_{conn}): 0.1 (c) cable loss, max: 3.4 (dB/km @ 850 nm)	Channel Insertion Loss (dB maximum)	1.5	**1.7**	1.8	2.0	2.1
	Safety Factor (dB minimum)	1.0	0.8	0.7	0.5	0.4
Industry Average Channel (a) loss/connection (μ_{conn}): 0.2 (b) loss/connection (σ_{conn}): 0.25 (c) cable loss, max: 3.75 (dB/km @ 850 nm)	Channel Insertion Loss (dB maximum)	2.2	**2.6**	2.9	3.2	3.5
	Safety Factor (dB minimum)	0.3	-0.1	-0.4	-0.7	-1.0
Industry Low Cost Channel (a) loss/connection (μ_{conn}): 0.5 (b) loss/connection (σ_{conn}): 0.2 (c) cable loss, max: 3.75 (dB/km @ 850 nm)	Channel Insertion Loss (dB maximum)	2.7	**3.3**	3.9	4.5	5.1
	Safety Factor (dB minimum)	-0.2	-0.8	-1.4	-2.0	-2.6

*Assumptions: Channel loss is the expected value at 850 nm for a 300 meter link, determined using a normal statistical model for the connectors calculated at two standard deviations (2σ) with the parameters shown in column 1. Note that the "Industry Average" and "Industry Low Cost" channels support only 220 meters at 850 nm because of the lower-bandwidth fiber used, and the performance at 300 meters is for comparison purposes only.

Table 1

Gigabit Ethernet Channel Insertion Loss Performance for Various Cable/Connector Systems

Fiber optic cable such as Lucent Technologies ACCUMAX® cable is available with maximum loss of only 3.4 dB/km. Also available are SFF connectors, such as Lucent Technologies LC with mean insertion loss of 0.1 dB and standard deviation of 0.1 dB. The calculated channel insertion loss for this combination with three connections is only 1.7 dB, allowing 0.8 dB of margin (Table 1, Lucent Technologies "OptiSPEED[2] Channel"). Using low-loss SFF connectors and low-loss cable result in channel insertion loss almost 50% lower than that obtained with cable and connectors meeting minimum industry-standard requirements. Therefore, this link will operate reliably with popular, less expensive short wavelength Gigabit Ethernet electronics for a full 300 meters.

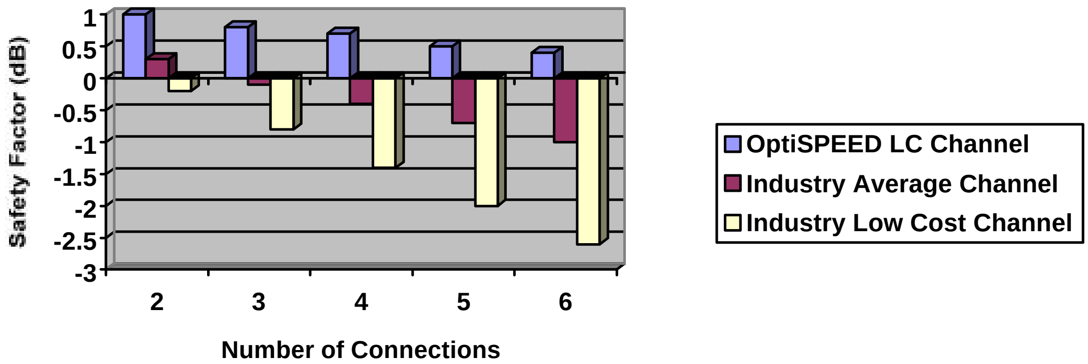

Figure 2

Gigabit Ethernet Channel Insertion Loss Safety Factor (300 m, 62.5 μm, 850 nm)

Figure 2 graphically depicts the margin or safety factor shown in Table 1 and demonstrates how both the "Industry Low Cost" and "Industry Average" channels may not be able to support Gigabit Ethernet operation for 300 meters with as few as two or three connections, respectively.

Specifying low-loss SFF connectors and low-loss cable gives network designers the latitude to design longer links or links with a greater number of connections. This allows not only greater flexibility in today's designs, but offers a longer life span for the cabling system infrastructure as speeds increase, and, potentially, link power budgets decrease. Selection of low loss SFF connectors and cable today can avoid costly replacement of higher loss SFF connectors and cable in the future. This can greatly reduce the cost of migrating from 10 Mbps Ethernet and 100 Mbps Fast Ethernet to Gigabit Ethernet. Channel performance is, therefore, a true indicator of system margin and upgradability, and should be carefully analyzed before making a major connector/cable commitment.

Connector and Cordage as a System

Although the new SFF connectors are 50% smaller than earlier connectors, more can be done to reduce the space requirements for a complete private network fiber cabling system infrastructure.

Small-diameter cordage is available to further minimize congestion at the desktop, in telecommunications closets, and at the main cross-connect. The diameters of most fiber optic cordage are either 2.4 or 3.0 mm; these diameters are too large for high-density applications. Robust 1.6 mm diameter cordage is available to complement some SFF connectors. Duplex cordage is only 1.6 x 3.6 mm in a figure-eight design comprised of two single-fiber cords joined together, yet it has a pull-strength rating of 100 lbs. A 56% space reduction compared to 2.4 mm cordage and 72% compared to 3.0 mm cordage is possible using 1.6 mm diameter cordage. A system designer should make sure that any small cordage meets all industry specifications for intra-building optical fiber cable. It is also a good idea to ensure that the SFF connector being considered is designed as part of a jumper system compatible with 1.6 mm diameter cordage. Lucent Technologies MiniCord® 1.6 mm diameter cordage has been designed to work with the LC connector to achieve the maximum space savings and also meets all applicable industry specifications.

Today, many fiber optic jumpers are assembled by small companies specializing in such work. When manufactured with high quality connectors and cordage, and under good quality control, such jumpers provide an alternative, and potentially, lower-cost source for users. By virtue of their design, some SFF connectors are not field-mountable on cordage and therefore may not be available from small "jumper houses." A system designer should look for a SFF connector that is field mountable on cordage and is available from one of these small companies.

Business Considerations

More is required than a good connector design

System Licensing

Proprietary designs, whether in computers or connectors, often cost users more money than "open" designs supported by a number of manufacturers. It makes good business sense to choose a technology that can be broadly licensed to multiple manufacturers.

Some of the new small fiber optic connector designs are licensed on only a limited basis, if at all. For example, one design is available for license only in terms of its "form-factor", i.e., the general dimensions and shape of the connector. This means that while this connector will mate with another connector built around the same form-factor, internal construction details and performance may vary greatly. Another SFF connector offers only the "behind-the-wall" component for licensing; the connector plug and jumper are proprietary.

Since some of these new connectors may incorporate technology obtained from a number of different sources, multiple licenses may be required to use the complete technology embodied in the connector. For example, the connector may comprise pre-polished fiber optic stub technology from one manufacturer and ferrule technology from another. This tends to add a level of complexity to the licensing process, and possibly higher costs. The savvy designer will look for products offering broad, single-source licensing of the SFF connector, adapter, and jumper.

Product Availability

The marketplace for SFF connectors is evolving rapidly. Some manufacturers announced their products late in 1996 and aggressively began promoting them at that time. Others took a more cautious approach and did not begin to fully market their connectors until both multimode and single-mode products were available in volume. Currently available SFF product offerings range from designs for which only multimode connectors and jumpers are available, to full product families supporting both multimode and single-mode applications. These product families include pigtails, adapters and panels for outlets and cabinets. When making a connector decision, a system designer is wise to verify that the full range of products required for current and future applications are *currently being shipped*.

Standards-based Design

The EIA/TIA 568A standard today specifies either the single-fiber or duplex SC connector for all locations within a building for termination of 62.5 µm multimode and 8.3 µm single-mode optical fiber. A migration plan is also defined for installations currently using ST connectors to continue to use the ST.

In early 1998, the TIA TR 41.8.1 Fiber Optic Task Group decided not to select a specific SFF connector to replace the SC in the upcoming revision of the standard, 568-B. Rather, the committee voted to work towards a performance-based specification. Work on that revision is still in progress. The TIA's new focus indicates recognition of the fact that there is clearly a difference in SFF connectors, and performance is the basis of that difference. So, it is recommended that anyone involved in a SFF connector decision look closely at performance specifications.

Summary

The best choice requires evaluating all the important factors

After reviewing various SFF connector design characteristics, how the connector is an integral component of the cabling system infrastructure, and the business ramifications of the choice of connector, it is apparent that connector selection is a very important decision. The good news is that manufacturers are finally addressing what has been one of the major impediments to widespread deployment of fiber optics in private networks: lower port density and resulting higher costs compared to copper systems.

Progress in most technologies, despite all the advertising claims, is generally evolutionary, not revolutionary. Fiber optic connector design, to a great extent, has followed the evolutionary model, but some of the SFF fiber optic connectors on the market today incorporate revolutionary technology. It would be prudent to examine such connectors very closely, matching current and future performance requirements, and if there is a mismatch, look elsewhere.

The ideal SFF fiber optic connector should be small, easy to field mount, compatible with all standard fiber types, high-performing and available at reasonable cost. It is the opinion of Lucent Technologies Bell Laboratories that fast-curing, adhesive-mounted, 1.25 mm ferrule-based connectors offer the best mix of performance, ease-of-use, and cost for today's private networks, as well as those that are rapidly evolving. The Lucent Technologies LC is such a connector. When combined with Lucent Technologies standards-based, low-loss, high-bandwidth premises cables, the LC connector offers the superior channel performance that insures the longest life expectancy for a private network cabling system infrastructure.

For more information, please consult your Lucent Technologies sales representative or call 1-800-344-0223, Extension 3070.

For Fiber Optic Products technical assistance, please call 1-888-FIBERHELP (1-888-342-3743).

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[2] OptiSPEED is a trademark of Lucent Technologies, Inc.