LC CONNECTOR- THE EMERGING CONNECTOR CHOICE IN CURRENT AND FUTURE APPLICATIONS

Curtis Hill
Verizon Communication Inc.
1095 Avenue of the Americas
New York, NY 10036
Voice: 212-395-3626
Fax: 212-398-5458
Email: curtis.hill@Verizion.com

Alberto Aponte
Lucent Technologies
2000 Northeast Expressway
Atlanta, GA
(770) 798-2895
(770) 798-2361
aaponte@lucent.com

ABSTRACT

With existing data traffic growing by 30 percent annually fueled by the explosive growth of Internet services and reductions in the cost of bandwidth, future service demand will only be satisfied by deploying the most advanced optical technologies. This need is particularly acute for future Broadband applications generating huge demands for reliable transport services, higher-density space utilization, and reduced provisioning interval. Utilizing a cost effective, proven multi-vendor “Small Form Factor” (SFF) connector that enables higher-density connector terminations with well-organized fiber management in a minimum amount of space is a solution whose time has come. Other factors that will become extremely important for Service Providers are long-term-reliability and product availability. When a connector in a backbone channel fails (e.g., optical performance degradation, unintentional disconnect, etc.), and its repair or replacement is delayed, then the potential size of lost revenue could be catastrophe depending on the application and the customers affected. In addition, some applications, such as emerging long haul systems, Dense Wavelength Division Multiplexing (DWDM) transmission, supporting Fiber-to-the-X (including Building (FTTB), Desk, Home, etc.), and higher bandwidth access to the home will demand more robust connections providing repeatable insertion and return loss. Given that every 1 dB of loss in the system results in 3-5km of reduced effective distance, a low loss connector translates to more distance between repeaters and more area coverage without expensive signal regeneration. Furthermore, as Service Providers begin to deploy services, using Passive Optical Network (PON) applications to provide Fiber to the Floor (FTTF) and Fiber to the Home (FTTH), the demand for a user-friendly and reliable connector will increase.

INTRODUCTION

As technological advancements are made in fiber optics, the change over from current to the next generation optical infrastructure and transport will influence the development and application of new optical components and technologies. While most service providers (RBOCs, CLECs, DLECs, ILECs, IXCs and PCS/Wireless Carriers) may not always agree on the same strategy as to what optical components to deploy or which technologies to use, to stay competitive they must design, build and deliver network solutions that meet current and future needs of their customers. The ability to accurately position the network to provide communication solutions to support emerging customer needs determines long-term profitability and viability. Service providers who plan for the short term can find themselves continually rearranging or overlaying their networks because they failed to invest in the best hardware and capabilities early. Whatever strategy, component, or technology is deployed, it is often chosen to reduce cost, increase efficiency, and to deliver superior services. However, there are as many optical networking strategies, components, and technologies as there are vendors and each selection is certain to have profound impact on the network infrastructure and level of service provided. Therefore, this paper will recommend a solution to help future-proof the fiber infrastructure and maximize the use of current and future fiber network investments. To accomplish this we will discuss the use of the LC fiber connector in current network designs and for future applications.

NETWORK CONSIDERATIONS

To accurately position the network for growth and to maximize the efficient use of the fiber infrastructure requires the following considerations:

- Design and build more recovery enabling architectural fiber infrastructure.
- Identify innovative commercially viable new products supported by multi-vendors.
- Build with the ability to respond to business opportunities and technology changes.
- Standardize on proven products that offer extended service life and deliver operation flexibility.
- Utilize new SFF fiber connector technology to reduce overall fiber termination space requirements.
- Select only those products that meet or exceed established industry standards and have successfully completed third party testing.
- Deploy only the most efficient and cost-effect passive optical components in the infrastructure.
- Use products that offer multiple connection configurations and backward compatibility design.
- Recognize that package design and size are important but being the smallest or the largest does not equate to being the best for most applications.
- Select universal product adaptable to support applications either in Singlemode or in Multimode.

EMERGING APPLICATIONS

The robust SFF connector has the ability to simplify the joining of fibers and to help reduce fiber infrastructure build and network cost. Utilizing the SFF LC as a universal connector enables the full range of fiber installation and connections needed to support vertical, horizontal and backbone applications. Strategic investment in SONET OC-192/768 and 40-Gbits/s DWDM technology can greatly increase the ability to meet demand for additional capacity with less fiber deployment. For example, some DWDM systems are now proposing up to 160 channels transmitted per fiber, significantly increasing the number of optical ports per circuit pack in the platform. Consequently, these newer applications are generating a need for smaller user-friendly connectors and fiber-cordage to help minimize the amount of equipment shelves and valuable space required. Other applications generating increase fiber terminations include Competitive Local Exchange Carriers (CLEC) leasing space from network providers for their fibers. The available amount of space for expanded collocation (shared space) is limited, so it drives the need for higher density within standard equipment bays and shelves. Going forward, FTTX (e.g., FTTH, FTTB, and FTTF) applications must now begin to plan for SFF connectors to bridge the gap between legacy and next-generation optical networks. This is needed in view of the fact that existing Central Offices, HUTs, CEV's, Equipment Rooms, cabinets and other remote terminals space will be exhausted faster if Service Providers continue to install new fibers with outdated embedded connectors. When the existing fiber termination capacity is full, gaining additional right-of-way for new space to build and install new termination sites will be costly. The LC SFF connector is best in new or existing applications because it is half the size of other embedded fiber connectors, such as SC, D4, Biconic, FC and ST® connectors. It also reduces finger and working space requirements that improves the fit to printed circuit board. Deploying the LC can help reduce optical network cost and eliminate the growing fiber termination problem.

Providing multiservice transport or broadband access is extremely important for Service Providers. Therefore, optical component performance reliability, availability, ease-of-use and robustness are near the top of their implementation list. High bandwidth demands is forcing both local and long haul backbone network providers to consider deploying new technologies faster. Providing integrated services and implementing other emerging applications will force increases in the bandwidth per fiber exponentially. Many applications demand a reliable connector with low insertion and return loss. “Low loss connectors” translate to a lower cost network with more distance between repeaters and more area coverage without expensive signal modifications and regeneration. Manufactures have demonstrated that the LC connector singlemode insertion loss and return loss are 0.08 dB on average and better than 55 dB, respectively, representing best in class optical performance. Fiber connector long-term optical and mechanical performance has always been important to the network interoperability because it also offers more options and greater flexibility in the network design. In the near future, high bandwidth carrying connectors will need to be so reliable that they may never lose their design performance threshold. Consequently, today some long-haul providers require the use of very reliable and robust connector such as the LC for their network.

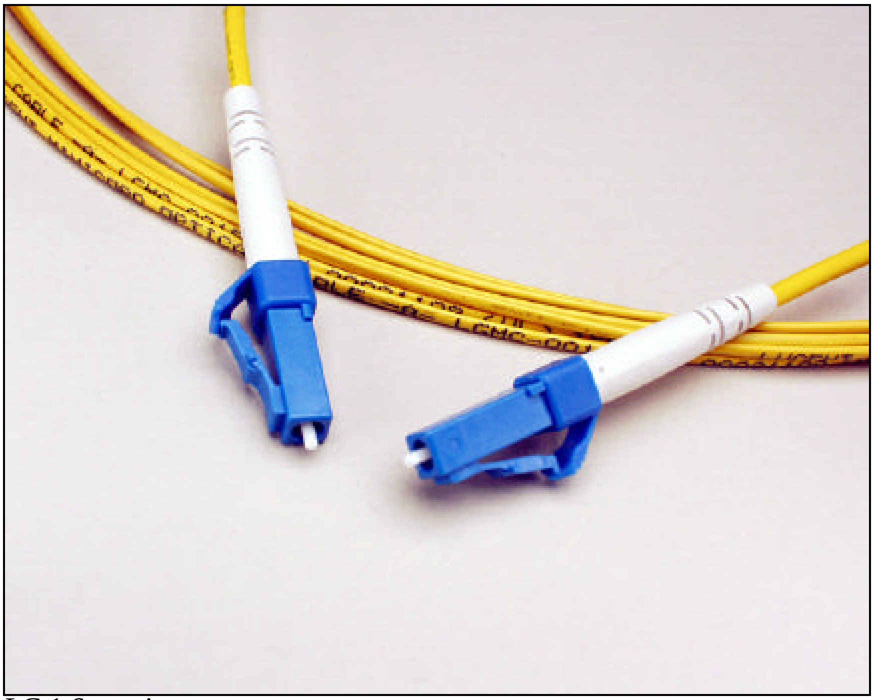
As the Service Provider gets closer to serving the customer, with PON applications, Fiber to the Desk (FTTD) and FTTH, the demand for a user-friendly and reliable connector is increasing. The LC is a simple quick-connect connector with trigger mechanism to help prevent the connector from snagging or unlocking when jumper cables are being routed. This improved version of the familiar, user-friendly existing SC connector and RJ45 telephone plug provides a reassuring audible click when engaged as positive reinforcement that the connector has been installed properly. This feature is particularly important to technicians and end user of applications such as FTTD and FTTH. The LC connector’s user-friendly design simplifies moves, additions, and upgrades to the network and provides an intuitive feel of assurance to the end user customer.

The following subtopics will discuss the three main features discussed above: size, optical and environmental performance and ease of use.

Small Size

The LC connector family is half the size of existing connectors, and uses a standard 1.6 or 2.0-mm diameter cable. The LC connectors feature a 1.25-mm diameter ferrule, half the diameter of the standard 2.5-mm ST and SC connector ferrules (2.0-mm for D4 ferrule). The dimensions of the LC simplex adapter are 6.9- by 11.5-mm, and the dimensions of the LC duplex adapter are 13.0- by 13.0-mm. This connector was designed to solve issues that equipment vendors and Service Providers have with embedded connectors. This small form factor connector will give equipment vendors a compact design option to free up valuable board space. One common application is Optical Demultiplexers/Multiplexers Units (ODU/OMU) used on Dense Wavelength Division Multiplexers. Some of these units have up to 160 channels, and, from a space perspective, it would have been impossible to design such units with connectors like the SC, FC, and ST, and 3.0-mm diameter cable. For example, if the ODU’s height is 13.23 in (336 mm), the maximum number of LC terminations that can be stacked vertically is 50 (25 duplex adapters) while the maximum number of SC connectors would be about 35. These numbers would be assuming there is no space between adapters, and no empty space above the top connector or below the bottom connector.

For Service Providers, especially RBOCs and CLEC’s, where space can be limited and very expensive, the LC is the perfect choice. The goal is to increase the number of fiber terminations within the same space they are currently using, or reduce the space they are using for their existing number of terminations. With the LC, users will be able to double the density (terminations per square footage), and thereby reduce the number of their bays, equipment, shelves, panels, and modules. However, more importantly, it allows those collocating to reduce the monthly cost of the leased space. Other examples of space constraints are found in COs Huts, Remote Terminals, CEV’s, manholes, cabinets, closures, regenerators/repeaters sites, and special equipment rooms. On virtually all applications, the LC is backward compatible with the SC.



LC 1.6-mm jumper

In order to maximize density, the cable diameter used with the LC connector has been reduced. The 1.6-mm cordage is the smallest in the industry and helps the user reduce congestion in any termination space including the fiber distribution frames and cabinets. It also makes it easy to perform rearrangements as the user can get easily to the connectors. The smaller diameter duplex fiber cordage is 1.6 by 3.6-mm in a figure-8 design that has two single fiber cords joined together with a web. Both fiber cordages, simplex and duplex, are rugged and robust. The cable diameters of the most widely used cordage are 3.0-mm and 2.4-mm, which are too large for high-density applications. Using the LC with this 1.6- mm fiber cordage, congestion at the Fiber Distribution Shelves and cabinets can be reduced, saving space over the 2.4-mm cable by 56 percent or 3.0-mm diameter cable by 72 percent. This permits 2.25 to 3.5 times more cords in the same cross-section trough. Cordage with 2.0-mm diameter can also be used with the LC connector.

Fiber Distribution Shelf with LC 1.6-mm jumpers.

Fiber Distribution Shelf with LC 1.6-mm jumper

Fiber Distribution Shelf with SC 3.0-mm jumper.

Optical and environmental performance

In order to meet customer expectations, SFF connectors must meet the existing mechanical and environmental performance level used in the industry today. The LC connector is designed to meet industry requirements for both multimode and singlemode. The requirement for average multimode loss is 0.5 dB and the maximum loss is 0.75 dB. The Telcordia requirement (**GR-326-CORE**, *Generic Requirements for Singlemode Optical Connectors and Jumper Assemblies*) for average singlemode loss is 0.2 dB and the maximum loss is 0.4 dB. Typical LC connector multimode performance results in average insertion losses of 0.1 dB, and can support above the standard reflectance requirement of –20 dB. Typical 6 positioned tuned LC connector singlemode performance results in average insertion losses of 0.08 dB, with a maximum insertion loss of less than 0.3 dB and a reflectance level of better than –55 dB.

New connectors must be robust and mechanically stable to withstand the day-to-day infrastructure environment. The LC connector has been subjected to a long list of environmental and mechanical tests.

Table 1: General Test Procedures for Jumpers

Tests	Conditions
Performance of Insertion Loss and Return Loss	Baseline performance to satisfy requirements
Damage	Baseline damage free connectors
Thermal Aging	85°C, uncontrolled humidity, 7 days long
Thermal Cycling	-40°C to 75°C, uncontrolled humidity, 7 days test duration.
Humidity Aging	75°C, 95% RH, 7 days long
Humidity / Condensation Cycling	-10°C to 65°C, >90% RH at interval four 65°C and interval eight 23°C. 7 days.

Tests	Conditions
Flex Test	Fibers attached to the connectors are to withstand a flex test of 100 cycles with a 0.60 kgf (1.32 lbf) load. The load is to be applied and removed gradually to one fiber at a time at a distance of 1-meter (3 feet) from the connector body. Each flex cycle shall consist of a 180° motion to one side followed by another 180° motion back to the original position. The sweep angle with respect to the connector body shall be 180° (side-to-side) during the test while maintaining a constant tensile load on the fiber to stress the fiber-to-connector interface.
Twist Test	Fibers attached to the connectors are to withstand a twist test of nine cycles with a 1.35 kgf (3.0 lbf) load. The load should be applied and removed gradually at a distance to 3 cm (1 inch) from the interface point. The twist axis should be normal to the component body and in line with the fiber axis. Each twist cycle shall consist of 360° rotation (horizontal plane) in one direction, a 720° rotation in the opposite direction, followed by a 360° twist to return to the initial position.
Proof Test	Fibers attached to the connectors are to withstand a straight pull load of 4.5 kg (10.0 lbf) for 5 seconds. Remove the load after 10 seconds. Repeat this test for 90° with a 2.3kgf (5.0 lbf) load. The load is reduced to 1.5 kgf (3.3 lbf) for Small Form Factor Connectors.
Transmission with Applied Loads (Media Type 1)	Subject the connector system to applied loads of 0.25 kg (0.55 lbf); 0.7 kg (1.54 lbf); 1.5 kg (3.3 lbf); and 2.0 kg (4.4 lbf) to the direction of optical axis (0°) by pulling on the fiber end 22 to 28 cm away from the connector. Repeat this test for 90° with the same loads. For Small Form Factor Connectors the load levels are reduced to 2/3 the value.
Durability	A total of 200 insertions are required.

The following table shows a representative sample of thermal aging.

Table 2 Summary of LC Jumper Optical Performance After Heat Aging

Wavelength	Mean IL Prior Heat Aging	Mean IL After Heat Aging	Change IL (Increase)	Mean RL Prior Heat Aging	Mean RL After Heat Aging	Change RL (Increase)
1310 nm	.08 dB	.11 dB	.03 dB	58.68 dB	60.83 dB	2.15 dB
1550 nm	.05 dB	.06 dB	.01 dB	61.31 dB	62.45 dB	1.14 dB

Good mechanical strength is achieved with a one-piece pull-proof connector design. Aramid yarn is included in the cordage and is designed to attach to the connector housing. A pull-proof design helps prevent the ferrule from pulling back from the optical plane when normal load is applied to the fiber cable assemble. This design also helps eliminate accidental disconnects or “crushing” when handling adjacent connectors. The user does not have to sacrifice mechanical performance to gain a higher density connector. This feature is very important on high-density facilities, especially on metro and access applications since rearrangements are more frequent. During rearrangements, technician may pull a jumper unintentionally this could cause some connectors to un-mate. However, if the connector is pull-proof in design it will support the end-face of the connector ferrule to remain optically connected under strain. Therefore, the LC will help protect the network from human errors and optical connector anomalies.

Ease of use

The LC connector uses the familiar insertion release mechanism similar to an ordinary telephone plug (RJ45 style). The LC connectors have been modified for easy insertion and disengagement. This is done by lengthening the latching arm, adding a finger nail catch and incorporating a trigger to the jumpers. The latching beam has been flexed over 1000 times by some LC manufacturers to demonstrate that the connector is robust. This should be no surprise since hundreds of millions of the standard telephone plugs are still in operation today.

The trigger on the jumper helps prevent the connector(s) from snagging when jumper cables are being installed or removed. The latching arrangement makes the connector easy to engage. The connector is pushed into the adapter and positively latched with a nice audible click. To disengage the jumper, the trigger is depressed and the connector pulls straight out; no special tool needed. There is no need to place your fingers around the connector, only on one side of the connector. This allows for denser connector spacing. The connector is also keyed; meaning it will only go into the adapter one way. This makes the optical performance very repeatable and the fiber end-face more durable.

In some applications, the technician may require a connector that is also field mountable. For instance, in a FTTH application, the drop fiber cable that is going to the house may be connected to the transponder in the house (or depending on another application, it could be connected to the inside-the-house fiber cable). Therefore, if the drop cable can be connectorized in the field, the Service Provider will not have to worry about either ordering fixed lengths of cables or dealing with slacks of cables. Meanwhile, if the drop cable is connectorized in the factory, then that means that the cable has to be ordered at a fixed length and/or the Service Provider will have to deal with some slacks of extra cable. The LC Connector is easy to mount in the field for these applications. The small 1.25-mm ferrule requires less polishing time than a 2.5-mm ferrule.

STANDARDS

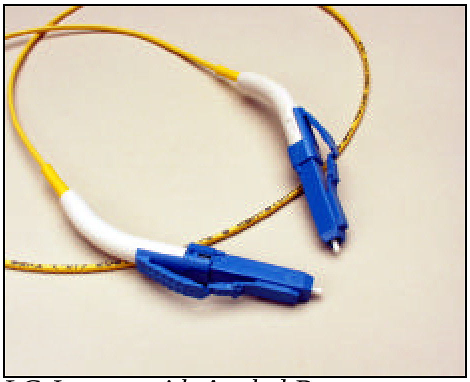
As mentioned earlier, the Service Providers and OEMs must select only those products that meet or exceed established industry standards and have successfully completed third party testing. As of today, the LC has been accepted on the 1394B S800 Standard (Home and Commercial Video). In addition, the following is a list of standards in which the LC is being incorporated:

- TIA Adopted an OPEN standard
- ATM Adopted OPEN standard for Gigabit
- IEC 86B WG 6 – CDV Stage
- IEEE802
- Infiniband Trade Association (Agilent, Nortel, etc…)

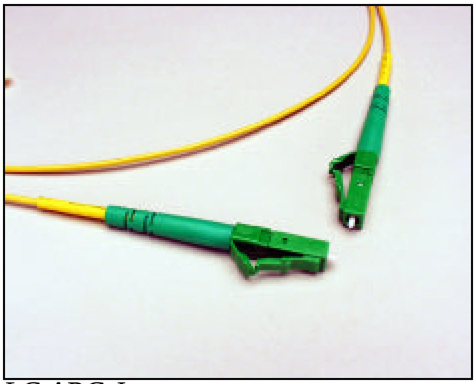
In addition, the LC connector has been designed to meet and has been tested to Telcordia GR326, *Generic Requirements for Singlemode Optical Connectors and Jumper Assemblies*

FAMILY OF PRODUCTS

Another factor when the Service Provider and OEMs are considering a connector is what other products are available that will provide flexibility. The family of product includes:

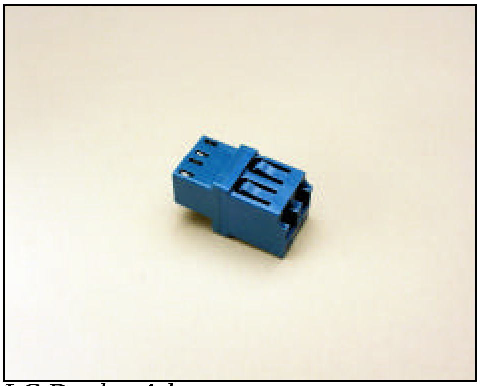


LC Jumper with Angled Boot



LC APC Jumper

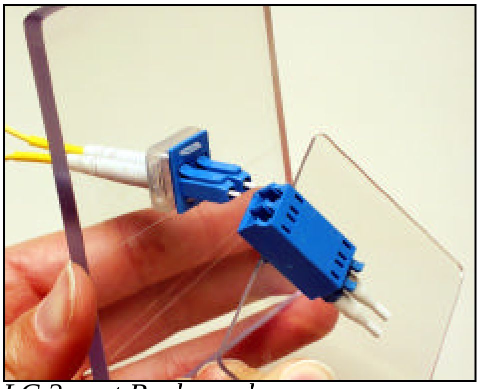
- Connectors -
  - Angled polish (APC)
  - Polish (PC)
  - Singlemode
  - Multimode
  - Simplex
  - Duplex
  - Angled boot
  - Straight boot



LC Duplex Adapter

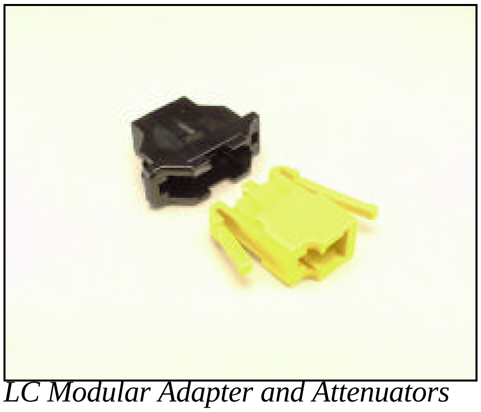
LC Duplex Angled Shielded Adapter

- Adapters -
  - Simplex
  - Duplex
  - Singlemode
  - Multimode
  - Angled
  - Shielded
  - LC duplex in SC footprint

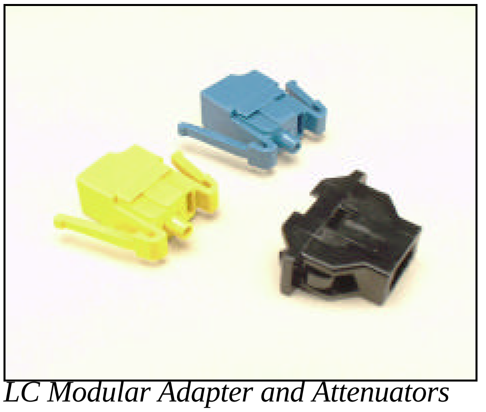


LC 2-port Backpanel

- Back panels -
  - 2-ports
  - 8-ports

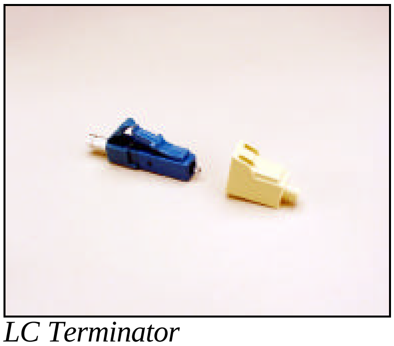


LC Modular Adapter and Attenuators



LC Modular Adapter and Attenuators

- Modular Adapters and Attenuators
- Build-on Attenuators
- Jumpers and Pigtails
  - LC to LC jumpers
  - Hybrid jumpers
  - Singlemode
  - Multimode
  - Simplex
  - Duplex
- Multi-fiber connector jumper
- Terminators



LC Terminator

COMPARISON OF CONNECTORS

The following table is a comparison of some types of connectors:

Feature	**LC**	**SC**	**ST**	**FC**	**MT-RJ**	**MU**
Performance	The LC is Telcordia compliant and meets industry optical, mechanical, and environmental standards. The design helps ensure end face contact (multimode easily meets 20dB return loss, and singlemode easily meets 55dB return loss). Insertion loss average 0.08 dB	Insertion loss average 0.2 dB Return loss minimum 55 dB	Insertion Loss average is 0.3 dB Return loss average is 55 dB	Insertion loss average 0.2 dB	Insertion loss less than 0.2 dB. In order to meet the 55dB return loss, the connector must be angled.	Insertion loss average 0.09 dB. Return loss average 50.3 dB
Product Offerings	See **Family of Products** section	Standard Singlemode Angled Multimode	Standard Singlemode Angled Multimode	Standard Singlemode Angled Multimode	Singlemode Multimode	Singlemode, Angled, Multimode
Availability	Available from multiple vendors	Available from multiple vendors	Available from multiple vendors	Available from multiple vendors	Available from multiple vendors (but not as many as LC and SC)	Available from multiple vendors (but not as many as LC and SC)

Feature	LC	SC	ST	FC	MT-RJ	MU
User friendliness	The connector uses the familiar RJ45 push-pull style housing, which allows disengagement in dense spaces. It is user friendly and an audible click sounds to let the user know the connector is engaged. This provides positive reinforcement that the connector is installed properly (intuitively obvious)	Push-pull style. Craft does not always know when the connector is fully engaged. Design requires fingers on cap when connecting or disconnecting.	Twist-lock bayonet. Design requires fingers on cap when connecting or disconnecting	Threaded cap, screw-on latching. Design requires fingers on cap when connecting or disconnecting	The connector features a reverse RJ-45 style latch, which has the same press-to-release of a modular connector.	This connector uses a push-pull mechanism similar to the SC design. Design requires fingers on cap when connecting or disconnecting
Ferrule Size	1.25 mm (cylindrical)	2.5 mm (cylindrical)	2.5 mm (cylindrical)	2.5 mm (cylindrical)	2.5 mm by 4.4 mm (rectangular)	1.25 mm (cylindrical)
PC finish	The process is familiar because the LC Connector is similar to existing products. Connector is easy to field mount and tune. It can be mounted on buffered fiber or cordage and it requires less polishing	The SC Connector uses a 2.5mm ceramic ferrule and can be polished the same as the LC Connector.	The ST Connector uses a 2.5mm ceramic ferrule and can be polished the same as the LC Connector.	The FC Connector uses a 2.5mm ceramic ferrule and can be polished the same as the LC Connector.	The surface has to be perpendicular to the fiber and use a plastic rectangular ferrule. The connector must be angled to get 40dB or better reflectance.	The MU Connector uses a 1.25mm ceramic ferrule. The MU Connector is not field mountable.

SUMMARY

The introduction of new optical technologies promise to increase bandwidth capacity and leverage the use of more optical components in the fiber distributing frames, switching equipment and routing systems to greatly increase speed and efficiency. Since optical equipment and the fiber infrastructure represents a major investment for communications service providers it is important that they build and maintain quality networks that can handle gigabits of data while simultaneously providing voice and video. Planning for future networks has become more challenging because customer requirements and service mixes have become unpredictable with the introduction of each new technology. Therefore, ongoing network management, fault location, testing, repair, and swift service restoration are still critically important. There are no single magic solution that can solve all of the networks connections problems, only the understanding that timely deployments of quality optical components is the best way of guaranteeing quality of service. The LC connector has features that will benefit the Service Provider on existing and future applications. Some of the benefits are fiber density,the opportunity for lower system cost, intermatability, backward compatibility with the SC, reliability, ease of use, proven robustness, multi-vendor support, and excellent optical performance. It supports both singlemode and multimode optical transmissions and is universal in adapting to virtually any fiber installation or application. The LC connector is cost–effective yet reliable to help future-proof the infrastructure. Whether you're a Service Provider or Manufacturer, the LC can exploit new designs or applications to function in control-environments inside of communication buildings as well as in the outside-environment including Outside Plant cabinets and closures.

ACKNOWLEDGMENTS

The authors would like to thank Yvonne Reeves, Norman R. Lampert and Amy E. Hauth of Lucent Technologies and Ron Zelins of Telcordia Technologies for their contribution to this paper.