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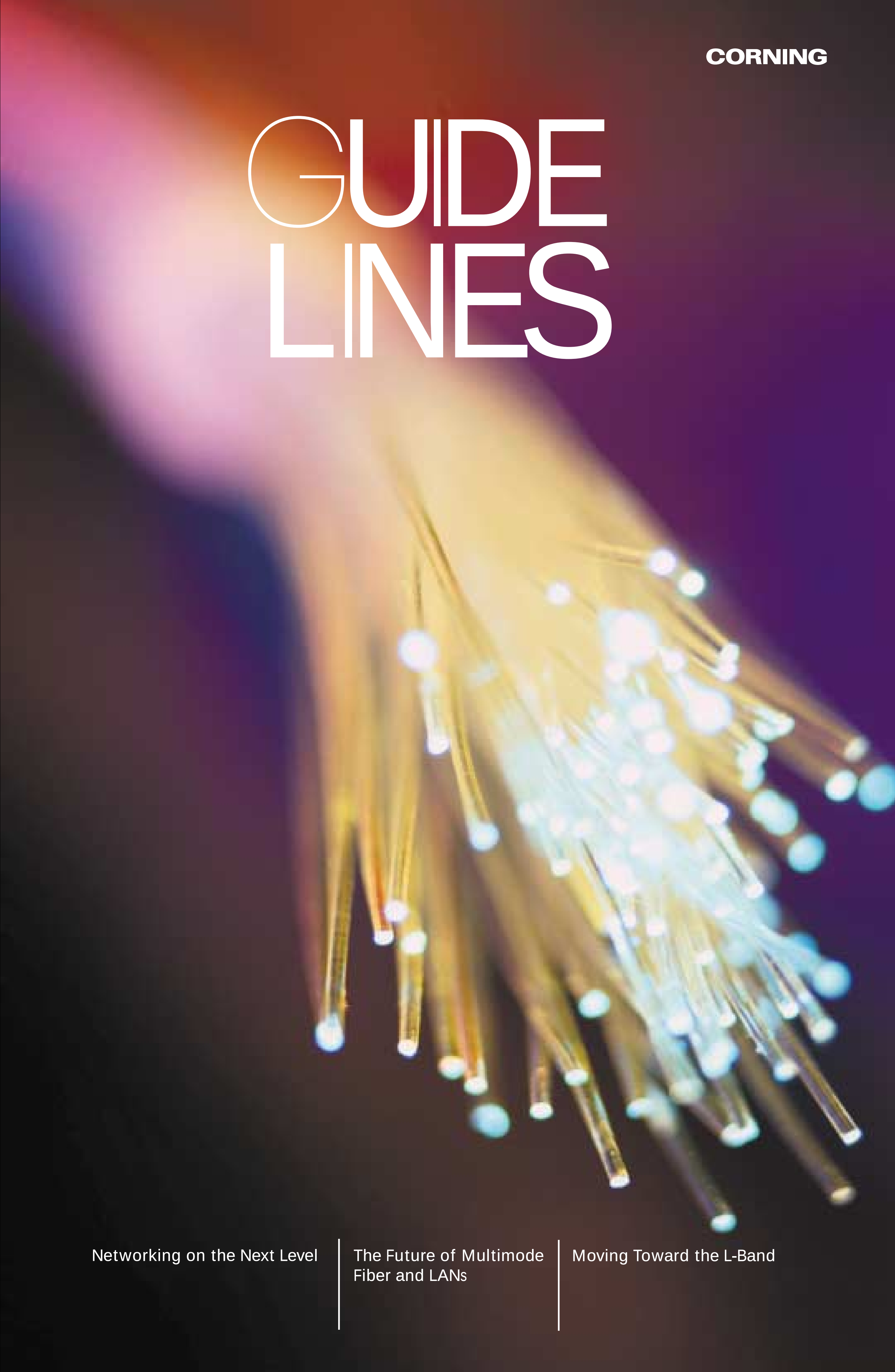


Networking on the Next Level

The Future of Multimode Fiber and LANs

Moving Toward the L-Band

Sarah Creath
EDITOR OF *GUIDELINES* MAGAZINE

Editor's Note:

Dear *GuideLines*® Subscribers:

In this issue, we bring to you a story on Williams Communications — a company that's building a network that's bigger than competitors' networks. We'll check in with Williams to see how that network will address customer needs. We also introduce Preston Buck, Corning's Premises market manager. Preston, Corning's own "show-me" engineer, answers questions on copper-versus-fiber to the desktop, Gigabit Ethernet and what he sees for the future of premises networks. "Moving Toward the L-Band," is an article by George Wildeman and Dr. Felton Flood — a Corning Incorporated manager and scientist who describe new technologies and opportunities in the long band.

If you'd like more information on any of the articles you see in this issue, please call the number listed at the end of each article. And let me know if you have any ideas about what you'd like to see in future issues of *GuideLines*. I can be reached at (607)974-4025 or by e-mail at creath-sj@corning.com.

Sincerely,

Sarah Creath

Sarah J. Creath

New Horizon Award 1999

The New Horizon Award, presented on October 28, 1999 at the Corning Incorporated CLEC Network Deployment Forum, honors one individual from the Competitive Local Exchange Carrier (CLEC) or Integrated Communication Provider (ICP) market for outstanding technological proficiency, business leadership and excellence in technology development.

Co-branded by the Association for Local Telecommunication Services (ALTS) and Corning Incorporated, the New Horizon Award commends one individual who has influenced well beyond the traditional parameters of her or his job function, exemplifies leadership and promotes a positive, progressive image for the CLEC/ICP industry.

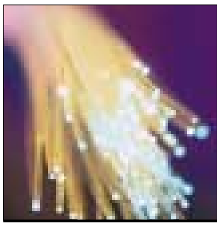
Phillip T. Kennedy, vice president of Advanced Products, Technology and Development and chief technology officer for McLeod USA is the well-deserved recipient, chosen from many tremendous nominations generated by the CLEC/ICP peer group.

As chief architect for the McLeod USA network in Cedar Rapids, Iowa, Phil led the design and deployment of a 16 switch, 200 node, 10,000-mile SONET network. In addition, he was responsible for the integration of cable television, internet, frame relay and ATM product development. This expansion can be directly correlated to the success of over one-billion dollars in capital raised on Wall Street and the solid reputation that McLeod USA has gained in terms of service roll-out and customer focus.

In addition to his technical expertise, Phil has maintained a humanistic approach that positively promotes the industry and the true drivers of success. He has actively educated both company employees and community leaders about the benefits of new technology and new telecommunication competition. While focusing on the temporal requirements of aggressive network deployment, Phil has kept the future in mind with a strategic 10-year plan and marketing strategy.

Congratulations to Phil on this richly deserved honor. He is a credit to his company and the CLEC/ICP industry.

BELOW FROM LEFT TO RIGHT: JOHN WINDHAUSEN, PRESIDENT, ASSOCIATION FOR LOCAL TELECOMMUNICATION SERVICES (ALTS); GAIL LAWYER, EXECUTIVE EDITOR, X-CHANGE MAGAZINE; PHILLIP KENNEDY, RECIPIENT OF NEW HORIZON AWARD, VICE PRESIDENT OF ADVANCED PRODUCTS, TECHNOLOGY, & DEVELOPMENT AND CHIEF TECHNOLOGY OFFICER, MCLEOD USA; JANE LI, MARKET MANAGER, CORNING INCORPORATED; DALE NIEBUR, DIRECTOR PRODUCT LINE OPERATIONS, CORNING INCORPORATED.



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GuideLines magazine is provided as a service to customers and end customers interested in the optical communications industry and in Corning's Telecommunications Products Division. The publication will keep you up-to-date on Corning's optical fiber products, fiber-optic industry trends, current measurement techniques, recent installations and case histories, and new literature available upon request. For additional copies, please call 1-800-525-2524 and refer to the extension code at the end of each article. *GuideLines,* LEAF and Corning are registered trademarks of Corning Incorporated. InfiniCor CL and SMF-LS are trademarks of Corning Incorporated.

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Winter 2000

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OPTICAL ENGINEER
WILLIAMS NETWORK

Networking on the Next Level

WILLIAMS HAS CREATED A NETWORK THAT PROVIDES AN ENORMOUS AMOUNT OF BANDWIDTH WITH COST-SAVINGS TO CUSTOMERS.

TODAY'S NETWORK TECHNOLOGY IS INCREDIBLY MORE ADVANCED THAN THAT OFFERED ONLY FIVE YEARS AGO.

Building a network isn't just about gaining connectivity; it's also about giving customers what they want — more connectivity and more options. Williams Communications (NYSE:WCG) is purposely building a network that's bigger and, according to Williams' engineers, better than the competitions' networks.

This is the second time around for Williams, which first entered the telecommunications industry in the mid-1980s when it built its first fiber-optic network. WilTel, a unit of Williams (NYSE:WMB), one of the nation's largest interstate pipeline companies, revolutionized the telecommunications industry when it placed fiber-optic cables inside decommissioned pipelines and along Williams' pipeline rights of way. Williams sold the WilTel legacy network in 1995 to a company known as LDDS, the precursor to MCI WorldCom. Now, following the 1998 expiration of non-compete restrictions that limited Williams' ability to sell interexchange services, Williams is building a network that's bigger and better.

What's the difference between Williams' new network and that of the legacy networks and the new market entrants? For one, the technology. Today's network technology is incredibly more advanced than that offered only five years ago. Williams is creating a network that provides an enormous amount of bandwidth with cost-savings to the customer.

The foundation of Williams' network is the most technologically advanced fiber on the market today, Corning® LEAF® optical fiber, which is optimized to transport multiple wavelength DWDM systems. LEAF fiber's chromatic dispersion characteristics, combined with a large effective area, act to minimize nonlinear effects such as four wave mixing, which can be problematic for high channel count DWDM systems. In addition LEAF fiber's low PMD values make it the ideal solution for long-distance OC-192 DWDM systems. Finally, its low loss bending performance and excellent splice-ability promote trouble free installation and a low cost of ownership. Williams began installing LEAF fiber in 1998. Prior to that, Williams used Corning SMF-LS™ fiber, a non-zero dispersion-shifted fiber first introduced in 1994.

Williams' network is based on a meshed optical networking technology with ATM at the core instead of a SONET-ring architecture — a key difference from competitors' networks. The optical strategy combined with Williams' meshed fiber network affords added flexibility by offering faster delivery of service and multiple service level options.

Other carriers have developed their networks around architectures that have multiple rings between different points of connectivity. To obtain optimal performance each ring must cover an area of 1200 kilometers or less. To gain nationwide connectivity, multiple SONET rings must be built and overlapped.

The biggest argument against rings is their limited efficiency. Going across multiple rings to set up a circuit requires reserving extra capacity around each ring to handle restoration in case of a fiber cut, and this can be very inefficient. The bi-directional line switched rings (BLSRs) are a method of SONET networking that sends half of the working network counter-clockwise over one fiber and the other half clockwise over another fiber. For areas where traffic demands are evenly distributed between the cities on the ring, BLSR rings are very efficient. However, due to the geography of the United States, building a nationwide domestic network using rings tends to be very inefficient.

While SONET rings offer the highest standard of restoration — 50 milliseconds (a very fast rate) — and are well-suited to metropolitan applications, their biggest problem is that they don't work that well with long circuits. Williams Network believes that when going between states or across long distances, as required for a backbone carrier like Williams, rings get too big to work well. The other issue is that some customers, depending on their application, do not always need the ultra-high restoration rate, and in the interest of cost-savings, may opt for a lower restoration rate.

SONET rings face numerous challenges to maintain that 50-millisecond restoration rate. SONET rings are not well-suited to accommodate more than 16 nodes or points-of-presence; the circumference of each ring has to be less

In-Service Plan

	Network	Cummulative Route Miles	FOP's	ATM Frame Relay IP Service Locations	Voice Switch Locations	Core Routers
1999	yellow line	26,000	△	● (orange)	■ (purple)	● (purple)
2010	red line	33,120	▲	● (blue)	■ (green)	

In-Service Plan Network Map

than 1200 kilometers, and to make use of shared protection bandwidth traffic, the rings must be evenly distributed between the cities on the ring. Due to these factors, rings are not good for building point-to-point connections over long distances, which is a particular challenge in the wide open spaces of the western United States.

Long-haul transport is Williams Communications' strength — and to combat the issues raised by the traditional SONET infrastructure, Williams has turned to an optical solution. This solution has given rise to industry acclaim — Williams has received the *America's Network* Readers' Choice Award and also has received the SUPERQuest Award for "Best Built Bandwidth" two years running.

Building quality bandwidth isn't just a matter of adding more fibers. The traditional SONET infrastructure does not provide efficient transport, while the optical solution does. The resulting cost savings enable Williams to offer more competitive pricing to its customer base.

Current SONET ring technology uses Add/Drop Multiplexers (ADMs) at the nodes. These ADMs act as both a switch and a transport mechanism, but typically the switch has limited capabilities. These switch limitations result in bottlenecks between adjacent rings and waste protection capacity (Figure 1).

Williams decided to use something different than SONET rings. By building point-to-point linear systems, we are able to simplify the transport layer of the network by eliminating switching in the transport terminals. We then use core SONET switches for grooming and restoration. The design of the network is much more efficient because protection capacity can be shared between routes, regardless of the distance. This efficiency also results in a lower network cost since we are only paying for grooming and restoration once in the core SONET switches, and these switches offer more flexibility than BLSR ring terminals.

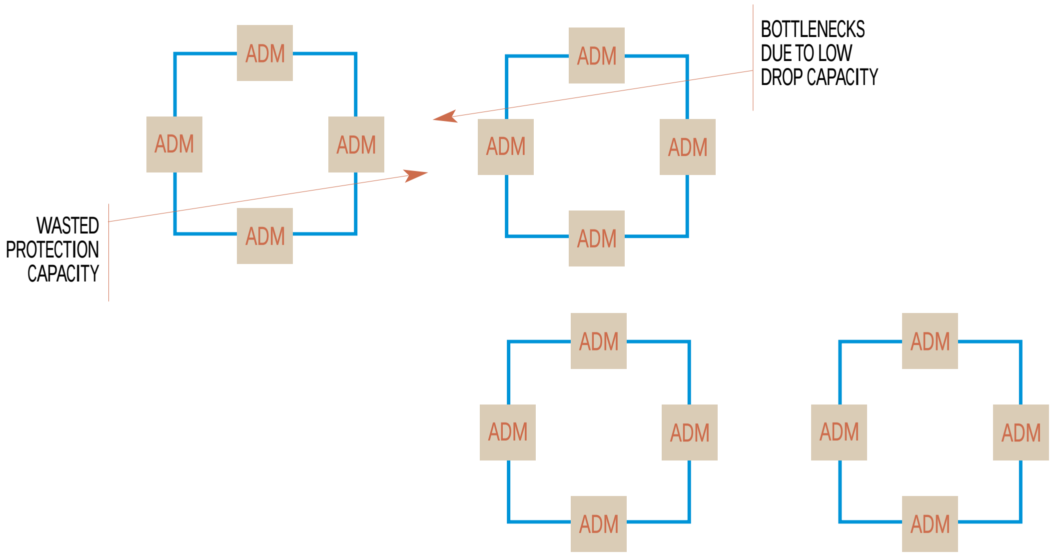
This philosophy allows Williams to build a more flexible, lower cost optical network than other carriers by minimizing the amount of capacity that must be reserved for protection. It also allows Williams to offer end-to-end provisioning of long circuits in a matter of hours instead of weeks. (Figure 2)

The core SONET switches offer different levels of restoration for ultimate flexibility. Williams can still offer customers the same ring-switched circuits that the other carriers offer with 50-millisecond restoration times, but what sets Williams apart is the ability to offer mesh-switched circuits with a 30-second restoration time at a lower price. Some customers will even choose to provide their own restoration switching to obtain an even lower price.

We've seen in recent years that, depending on the service, some people don't need the 50-millisecond restoration rate and consequently, don't want to pay for a high-end service they don't need. Internet service is a great example. We often don't mind waiting a few seconds for a web page to 'load' on the screen. We're willing to wait another second rather than pay premium rates for our own Internet service.

On the other hand, voice traffic will not tolerate delays and needs a higher restoration rate. By using Williams' network, customers can realize cost savings by choosing the levels of restoration service that best suit their applica-

Figure 1 Ring Inefficiencies



tions, rather than having to subscribe to the only level a carrier provides.

The Williams network introduced quality of service to the optical network earlier mid-year 1999 with the announcement of OC-48 wavelength services. This service allows customers to buy different levels of protection on an OC-48 wavelength along the coast-to-coast Williams Multi-Service Broadband Network™. Customers can opt to receive the "platinum" service level with 50 millisecond restoration rates or the "silver" service level that simply provides a wavelength for a customer's use with no restoration at all. The "silver" service level is generally the option geared for those customers that have an existing network of their own or that purchase concurrent capacity from other carriers. Early next year Williams will also roll out a "gold" service with restoration in less than three seconds. The "gold" service level is geared toward customers who do not have real-time traffic and want to lower the cost of building a nationwide network.

Our optical strategy and network architecture allow us to use our network more efficiently, which gives us a low-cost solution to offer our customers. This isn't something that our customers care about directly, but it is something that will affect our pricing. Other carriers will be forced to compete with Williams' pricing, but inefficiencies in their networks will require them to do it by reducing their profit margins. One reason many of our competitors do not subscribe to the optical strategy is because they are already deeply entrenched in a SONET ring architecture.

By the end of 2000, Williams' final network design will include approximately 80 SONET switches, each capable of switching 640 Gbps (gigabits per second). The first of these SONET switches are scheduled for installation in 4Q99.

Meanwhile, Williams is well on its way to completing its coast-to-coast mega-network. To date, Williams has more than 22,600 miles in the ground and more than 19,600 miles of fiber in service (see map).

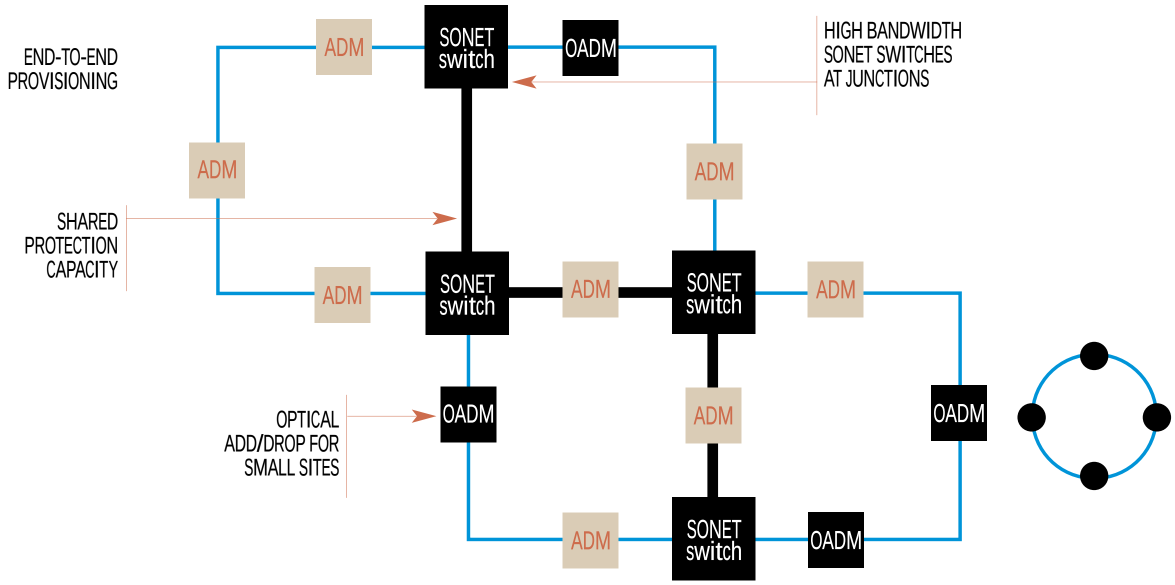
Williams expects to complete its 33,000-mile optical network by 2000. For more information on Williams, call 1-800-Williams or visit them online at www. williams communications.com. ▪

For more information

FROM *CORNING INCORPORATED*

To learn more about the Williams network and the advanced fiber-optic technology deployed within it, contact the Corning Optical Fiber Information Center at 1-800-525-2524 ext. 7556 and ask for R3118, an article reprint from *Lightwave* magazine entitled "Networking Firm Builds New Generation Nationwide Fiber-Optic Network" that was co-authored by Corning Incorporated and Williams.

Figure 2 Efficient Network Design



STRAIGHT TALK

WITH PRESTON BUCK

CORNING INCORPORATED'S MARKET MANAGER OF PREMISES APPLICATIONS and a 'show me, I'm from Missouri' guy gives his opinion on the future of multimode fiber and local area networks.

Copper's stronghold in local area networks (LANs) continues although its demise has been predicted over the past few years. What's the real story?

Copper's progression is very interesting. Many years ago, it started out simply as coax. Then different types of coax evolved that were upgraded to new coax to be followed by twisted pair, shielded and unshielded. Now there are all the different categories — CAT 3, CAT 4, all the way to CAT 7.

Basically, it's the same product, copper! Only now with different coatings or a different separation or twist, it is packaged differently and marketed as a new product. The copper manufacturers have been able to improve the performance enough to meet the latest protocol requirements and sell each improvement as an "upgrade." This has worked so far, but now, with Gigabit Ethernet (GbE) being adopted in the riser and spreading to the desktop, things will change. The standard for GbE over copper took a year longer to develop than the GbE over fiber standard. I think this reflects the difficulty of using copper at the higher speeds and the realization that a lot of CAT 5 isn't installed properly and doesn't work at GbE. This is why there are so many additional tests that are required to run GbE over CAT 5. And while there finally is a standard for GbE over copper, most network planners are recommending CAT 5E or higher. Why is this? And what are the actual differences between CAT 5 and CAT 5E? The answer is that there are different testing requirements and installation practices, but the materials that go into the cable essentially are unchanged. The dielectric insulation is thicker and the number of twists has been changed, but the conductor size is unchanged. So network owners must pay for the cost of re-cabling with a more expensive CAT 5E or CAT 6 cable and have more testing requirements and more rigorous installation practices — all in the hope that they can run GbE over copper successfully.

Over the next five to ten years, I think that copper will continue to have a large percentage of the desktop links. The cheaper short-term cost almost ensures it. But with GbE, I hope the industry is beginning to realize that "upgrading" their copper cable isn't really buying them that much. The "upgrade" still is basically the same material in a slightly different configuration. Perhaps it's time to truly upgrade the network cabling to optical fiber and reap the benefits for years to come.

Taking this into consideration, how do network designers continue to justify the use of copper?

The demand for copper-to-the-desktop has always been strong because of its perceived low cost. So short term, it's cost. But that's the irony of the situation. Too many of those working in telecommunications today are focusing only on installation costs. They're not looking at the whole picture — the total cost of a network.

All network costs must be taken into consideration: installation, testing, maintenance and upgrades. Installation costs for fiber cables are very near the cost of CAT 5 and are less than the cost of CAT 6. The fiber electronics still are more expensive than copper electronics, but thanks to small form factor connectors, the costs continue to drop. Fast Ethernet fiber network interface cards (NICs) can be bought for around $140 versus more than $300 a couple of years ago and media converter prices have dropped to about half of what they were a couple of years ago. So the cost of a fiber network isn't that much more expensive than a copper network. And if your network has centralized cabling, the installation costs can actually be less than a copper network.

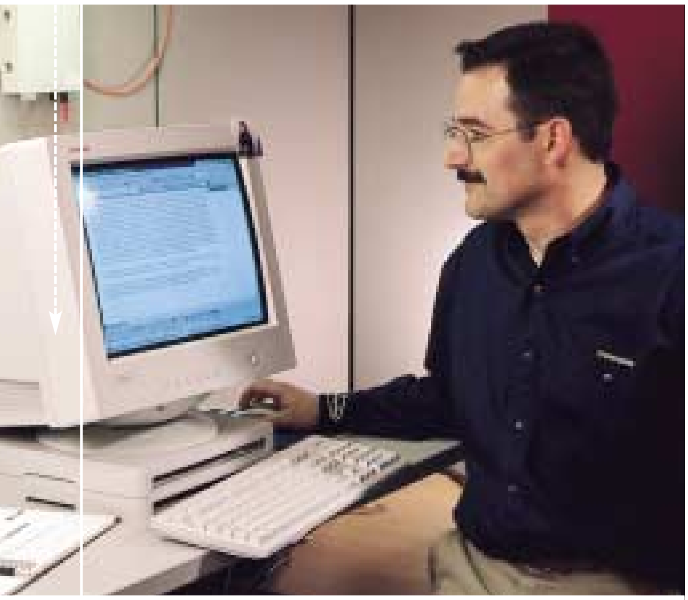
Testing fiber is easier and takes less time than copper. According to the TIA TSB-67 (Link Performance Test Standard), four tests are required for copper: wire map, length, attenuation and near-end crosstalk (NEXT). These tests are the bare minimum and aren't enough for GbE links. For GbE links, you need the following additional tests: delay skew, power sum NEXT, power sum ACR, far-end crosstalk and return loss. These tests cost time and money, especially the crosstalk test which should be performed at both ends of a link. In contrast, TIA 568A (Commercial Building Telecommunications Cabling Standard) requires that only the attenuation of a fiber link be measured. One simple test from one end of a fiber link is all you need.

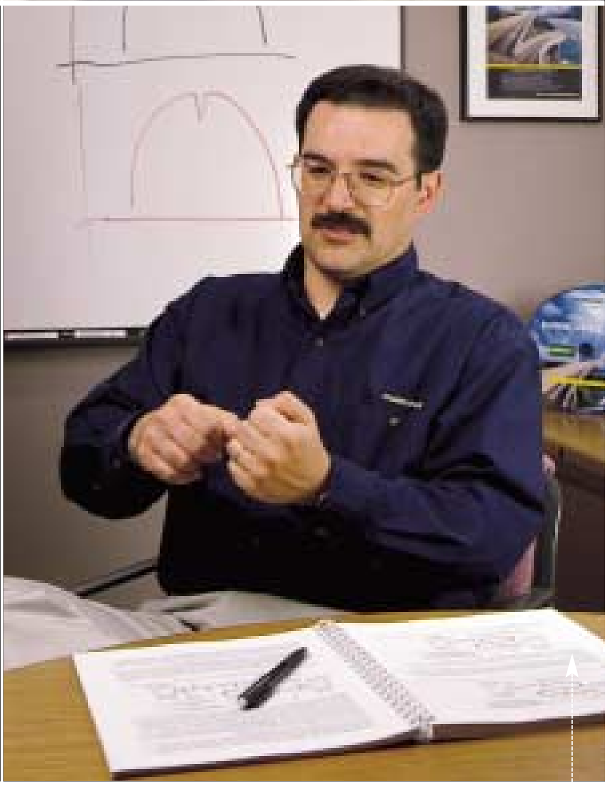
Maintenance costs of the network also are important to consider. How much time and energy do you spend fixing the physical layer? A fiber network needs less maintenance than a copper network simply because glass is inert. It doesn't oxidize, corrode or have galvanic reactions. Consequently, a fiber network is more reliable. In talking to switch vendors, I'm told that smaller companies tend to install fiber-to-the-desktop (FTTD) within 20% to 40% of the costs of a copper network. Because engineers with numerous other responsibilities usually manage the networks, they're looking for a maintenance-free system that's dependable for the long term. They don't want to waste time babysitting a copper network. In talking to Corning networking personnel, they confirm this makes their job easier. And there are certain aspects to which an exact cost cannot be assigned, like network downtime. Where does it go down? For how long? In what business? How is productivity affected? As you can see, it can add up to more money than the installation costs.

Unfortunately, many organizations are trying to hold on to copper technology because they don't want to pay the perceived high initial investment required to upgrade to fiber. But how many times have they upgraded their copper network in the past five or ten years? When you examine the total cost of the network over a decade and include recabling three or four times, a copper network is more expensive. When you look at the cost of recabling a copper network in terms of materials, labor and downtime, fiber definitely offers a better long-term return on investment.

Is anything being done to address fiber installation costs?

Yes, definitely. There's no longer the cost disparity between copper and fiber that there once was. The cost of a copper network is no longer half the cost of a fiber network. The gap between the two is closing fast. The cost of electronics is coming down. With the advent of new small form connector technology, end users are realiz-





CORNING HAS DEVELOPED A NEW SERIES of high-performance multimode fiber engineered specifically for laser-based LAN protocols.

ing higher connector densities and a decrease in cost.

Another major breakthrough is centralized architecture. This cabling design houses all of the data electronics in a single location with optical fiber cables providing direct connections to every workstation outlet in the network. Cost savings abound with this type of design. Without the need for numerous, expensive telecommunications closets, money is saved by reducing the amount of real estate and the need for as many active electronics. Maintenance costs plummet as well.

Copper, on the other hand, requires all of these closets because of the limited distance it can run, which basically is 100 meters. No matter which category of copper you buy, you still are limited to 100 meters. Every 100 meters, active electronics are needed to manage the signal, whether it's being repeated, trunked together or switched. With fiber, depending on what protocol is being used, the distance between active electronics can be as great as two kilometers — 20 times the distance of a copper network! The distance limitations of a copper network just don't apply to a fiber network. And don't forget that every piece of active electronics needs to have clean power, a good ground, conditioned air and uninteruptable power supply (UPS).

With centralized architecture, it's also less expensive and easier for one person to manage a network from one place versus having many people responsible for different floors and different switches. Troubleshooting is much cheaper and simpler. Because of a direct path with less active electronics, there's no process of elimination and the problem can be located right away. For example, George Washington University went to a centralized fiber network, which they call "fiber to the pillow." They had 20 technicians maintaining their old copper network. Now one technician maintains their current fiber network.

Additionally, centralized architecture design is flexible. It doesn't necessarily mean having to run everything to one switch. For example, if I were cabling a 15-story building, I might not have enough space in the riser to send 3000 fiber pairs down to a central switch. But if I used fiber to each desktop and combined three communication closets into one and connected that one directly to the central switch, that's a step in the right direction. I would realize the benefits of reduced costs for real estate and fewer electronics to buy and maintain service. Or, as another alternative, I could connect every five floors to one hub. So there are many approaches to using a centralized architecture, and they all offer cost savings.

Are there other factors to consider when comparing copper vs. fiber?

Certainly, network reliability is a big one. Category 5, unshielded twisted pair (UTP) cable is the most common grade of copper cable in use today and it's plagued with problems such as installation errors, substandard cable materials and substandard connectors.

Many installation mistakes are due to the fact that standards weren't formalized until 1995, although you could buy CAT 5 cable as early as 1993. According to Jim Serenbetz and Pete Lockhart, Anixter Inc. officials, in their white paper, "Category 5: How Did We Get Here and Where Do We Go Next," a lot of improperly installed cable exists in buildings today.

CORNING IS ALSO WORKING ON WAYS TO DRIVE THE COST OF ELECTRONICS DOWN, therefore helping to increase the acceptance of fiber-to-the-desk.

They mention in their paper that in 1994 the demand for Category 5 UTP led to shortages of a critical material, FEP, a form of Teflon used as a dielectric. Some cable manufacturers produced cables using less FEP on one of the twisted pairs, having mixed it with other materials that were compliant with the standard. The result was dramatic variance in electrical performance. Additionally, independent lab tests found that four out of ten connectors sold as Category 5-compliant failed to meet specifications and several others were borderline passes. All these problems add up to reducing the reliability of your network.

Fiber doesn't have any of these problems. Fiber-optic cable is relatively straightforward to install. There aren't any twists to count or three-eighths inches of insulation to remove. The jacketing materials are there to support and protect the fiber. They play no part in the transmission of the light and cannot affect the performance of your network. It's the same with the connectors. The function of a fiber connector is to bring the end-face of the fiber into contact with either another fiber or an active device. Unlike a copper connector, a fiber connector is not part of the transmission path. The current fiber connectors are easy to install and usually come with a tool kit that makes installing connectors much simpler and faster than in the past. Followed with a simple test for attenuation, a fiber-optic link is hard to beat.

All these things contribute to making your fiber network much more reliable. Incidentally, this is why all the transaction data from the New York Stock Exchange is transmitted on an all fiber network.

We've talked about cost and reliability. Is there anything else to consider?

Meeting the challenge of the future is a huge consideration. In the past decade, LAN data rates have more than doubled, which has led to the adoption of a new protocol, Gigabit Ethernet, the third generation of Ethernet technology. GbE offers 1000 Mbps speeds in LANs and upgrades easily from Ethernet, the current protocol most organizations are using. It's expected that GbE will be commonly used in both riser and backbone links within the next two years. Eventually it will migrate to the desktop as well. Apple already offers a GbE card as an option on their latest computer, the G3, and Phobos currently offers a GbE fiber NIC for desktops.

Supporting this, an Infonetics Research study released this spring stated that in all sizes of organizations, GbE is connecting servers, backbones and even desktops in numbers equal to asynchronous transfer mode (ATM) and will exceed ATM in 2000. And 68% of study respondents see it as a substitute for FDDI and ATM. So it looks like most networks will need to be able to support GbE.

How else is GbE different?

Traditionally, LAN applications used light emitting diodes (LEDs) for light sources. GbE, however, utilizes laser light sources such as 850-nm vertical cavity surface-emitting lasers (VCSELs) and 1300-nm Fabry-Perot lasers. This is an important distinction: while LEDs distribute their power throughout the entire index profile of the fiber, propogating hundreds of modes, lasers distribute power through roughly 5% at the center of the core and thus propagate fewer modes.

Will copper be able to handle GbE?

It's hard to say... . The standard for GbE over CAT 5 is out now. But by the end of 2000, many IT managers expect CAT 5 to be replaced because they don't know if their CAT 5 installations will handle GbE. They'll have to test for far-end cross-talk, return loss and delay skew problems they didn't have to worry about in the past. And unshielded twisted pair can be more costly to test than fiber. Most likely, copper in some form, will be able to handle GbE, though it will probably require recabling to a more expensive copper cable. Even then, the copper cable will still have a distance limitation of 100 meters.

What is Corning doing to meet the challenge of the future?

The GbE Standard (IEEE 802.32) formalized in June 1998 provides media specifications for both multimode and single-mode optical fiber. With single-mode networks being the more expensive option, Corning has developed a new series of multimode fiber — InfiniCor™ fiber. This high performance fiber is engineered specifically for laser-based LAN protocols such as GbE. InfiniCor fiber offers guaranteed GbE performance at established link lengths through associated cabler warranty programs and is compatible with existing multimode fiber and equipment. It's suitable for backbone, riser and horizontal applications. InfiniCor CL™ fiber, next in the series of InfiniCor fiber, eliminates the need for a mode conditioning patch cord traditionally required for 1300-nm operation and is designed to support higher speeds. Basically we have a series of fibers that you can run any of the existing protocols on such as Ethernet, FDDI, etc. And when you want to start running GbE, you can do so over the same fiber. No recabling is required.

Corning also is working with the Fiber Optic LAN Section, the MTRJ Alliance and the VF-45 Action Group. These multi-vendor organizations are working on ways to drive the costs of electronics down, therefore helping to increase the acceptance of fiber-to-the-desk.

How do you personally feel about the future?

I bought my first computer in 1984, and I have always been fascinated by fiber-optic technology. To be able to take an image, break it into bits of light, send it down a glass pipe, and then reassemble it at the other end as a complete image is simply amazing to me. It's a great time for fiber, and I see the computer-networking industry continuing to grow by leaps and bounds. Right now, as in the past, we're unsure of how we'll utilize the colossal bandwidths we're now capable of with new protocols like GbE. However, I have no doubt that in the not too distant future we'll look back and think that even 10 Gbps is slow and can't meet our needs. But our fiber networks will still be there to support us. ■

For more information

FROM *CORNING INCORPORATED*

To learn more about the future of multimode fiber and LAN, please call 1-800-525-2524 ext. 4158 and ask for the Centralized Architecture series of articles.

George Wildeman
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MOVING TOWARDS THE L-BAND

THIS ARTICLE APPEARED IN THE AUGUST 1999 ISSUE *LIGHTWAVE* MAGAZINE

Driven by the Internet and new datacom services, demand for bandwidth in long distance networks doubles at least every two years. Today, some existing long-haul fibers carry 50-100 Gbps per route, and traffic growth in many networks continues at rates from 30%-150% annually. These capacity requirements are pressuring traditional time-division multiplexing (TDM) based upgrade paths.

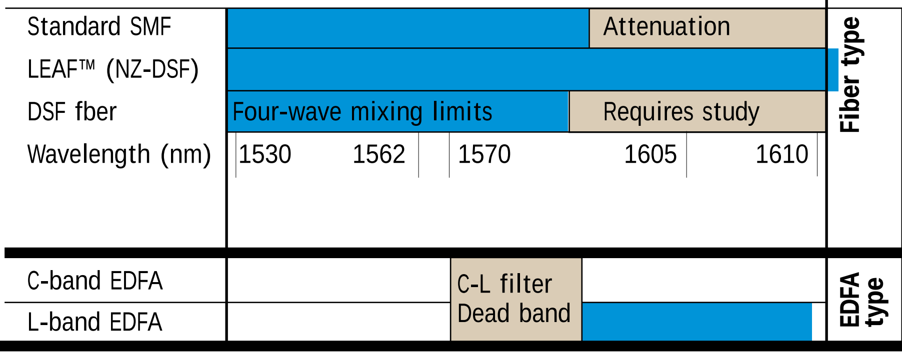
Technologies such as erbium-doped fiber amplifiers (EDFAs) and dense wavelength-division multiplexing (DWDM) have allowed system planners to meet current demand, but as advanced data communication systems proliferate, service providers continue to need more capacity at lower cost.

Fortunately, room for more bandwidth already exists in optical fiber. The conventional (C) wavelength band of EDFAs extends approximately from 1530 nm to 1562 nm, and has been used for the introduction of 2-, 4-, 8-, 16-, 32-, 40-, 80- and 96-channel DWDM systems since the introduction of EDFA technology in 1994. It's important to note the transmission window's range could become wider as amplifiers become more complex.

Recent interest by system operators in accessing more bandwidth (and in some cases different bandwidth) has drawn attention to new optical components designed to operate in the "long" (L) wavelength transmission window. L-band EDFAs provide an attractive option for expanding bandwidth. These amplifiers, operating in (approximately) the 1570- to 1605-nm wavelength window, add more room for channels in high-data rate systems. The additional channel bandwidth they supply also addresses nonlinear effects in fiber — a significant impairment that has prevented further increases in transmission capacity. Again, the range of the L-band could become wider as amplifiers evolve.

New generation of EDFAs assist with fiber exhaust, non-linearities and system cost

Table 2: **DWDM operating window for single-mode fiber types**



L-band Applications

Beginning next year, L-band amplifiers will be used in several DWDM applications. The availability of this new wavelength window creates opportunity for system designers to re-think their options. Potential applications for this window include:

- Extending the capacity of wavelength-exhausted LEAF® fiber and conventional SMF-fiber networks.
- Defeating the non-linear four-wave-mixing impairment inherent to dispersion shifted fiber (DSF)-based networks.
- Increasing wavelength channel spacing to take advantage of lower cost WDM multiplexers and transmission lasers.
- Creating unique bi-directional amplifier topologies using both the C and L bands.
- Segmenting different types of data in operating networks; dedicating the L-band for a specific service.

Design and Economic Considerations

L-band EDFAs will need to have similar form, fit and function as their C-band counterparts. The devices will be required to operate side-by-side with C-band amplifiers in 80-100 km spaced repeater huts. They will need to fit into the same equipment racks, be powered and controlled similarly, and face nearly the same optical gain, power and noise requirements as C-band amplifiers. Table 1 describes the similarities between C-band and L-band EDFA technology.

L-band EDFAs also will need to cost approximately the same as C-band amplifiers in high volume quantities, maintaining a similar $/Gbps/km prove-in point. The L-band amplifiers will, in most cases, be added modularly via bandsplitter and combiner technologies to existing C-band amplified systems. Combining the C-band with the L-band allows network providers to double the transmission window for wavelength division multiplexing from about 32 to 64 nm. Service providers can operate 40 to 80 channels or more at OC-48 or OC-192 in each band, a potential total capacity exceeding 1Tbps (1000 Gbps). The modularity also allows a "pay-as-you-grow" path for wavelength upgrades. Demand for L-band EDFAs is expected to begin in 2000.

Table 1 **C- and L-band erbium-doped fiber-amplifier technology**

EDFA type	C band	L band
Wavelength band	1530 to 1562nm	1570 to 1605nm
Transmission fiber attenuation	<0.25 dB/km	<0.25 dB/km
10 Gbit/sec channel capacity	40 to 80 channels	40 to 80 channels
EDFA component technology		
Isolators, taps, WDMs	Production	Production
C and L-band splitters	N/A	Development
Gain-flattening filters	Production	Development
Erbium fibers	Production	Development
Pump lasers	980nm, 1480nm	980nm, 1480nm

Upgrading Networks Built with Standard Single-Mode Fiber (SMF)

The L-band of conventional SMF fiber is a promising option for users interested in upgrading their legacy fiber networks. Many long distance and regional networks have insufficient amounts of installed standard G.652-type single-mode fiber (SMF). Median fiber counts range from 15 to 35 in global long distance networks, indeed some fiber cables have as few as 10 fibers installed. Choosing the L-band can be the correct economic decision in situations where users are leasing fibers and want to maximize the capacity on a fiber, or to avoid or delay the potential high cost of installing a new transmission cable.

There are a number of issues that should be explored when considering an L-band upgrade on SMF networks, including the onset of bending-induced loss of some earlier vintage fibers. Today, data gathering of outside-plant fiber cable is occurring in several long-haul networks to determine the actual attenuation performance of the L-band. Still, high-cabled attenuation from 1570 nm to 1610 nm is not expected to be a big issue for most of the installed network. In fact, several operators are moving ahead with plans to use the window and are absolutely counting on this window to access new bandwidth.

Advantages for Dispersion Shifted Fiber Networks

One of the early applications for L-band technology will be to alleviate non-linear effects that limit bandwidth capacity on DSF fiber. This fiber was designed with the zero dispersion crossing wavelength centered near the 1550-nm wavelength to optimize transmission signal attenuation and dispersion performance. Studies later revealed that this characteristic was the primary source of potential non-linear effects that appear as mixing-induced noise in DWDM applications. The number of DWDM channels on DSF practically is limited to less than 10 channels in the C-band due to four-wave mixing (FWM) non-linear effect. But at longer wavelengths the fiber exhibits non-zero dispersion, and is more fit for multi-channel DWDM operation. Table 2 compares the DWDM operating window for single-mode fiber types.

The L-band EDFAs may prove to substantially extend the bandwidth carrying capabilities of DSF-type fibers. In fact, some system operators with DS fiber networks may begin to use the L-band before the C-band. The L-band could become the dominant band for these fibers as operators look to minimize the cost of amplifier upgrades (C-band EDFAs would reach maximum capacity at much smaller channel counts).

This application is beginning to surface as users are exhausting the usable wavelengths of DSFs. What is needed now is a better understanding of this fiber's optical characteristics in the L-band, and the commercial availability of transmitters, WDMs and L-band amplifiers.

Next Generation Ultra-High Capacity Networks

In 1998 Corning introduced the next generation of optical fiber designed for ultra-high-speed networks. Corning® LEAF® fiber, a single-mode non-zero dispersion-shifted optical fiber, allows greater increases in power because of its large effective area. The effective area is the light cross section path of the fiber. A larger cross section reduces the intensity of light, thus decreasing non-linear interactions.

Corning has specified attenuation, macrobend and dispersion out to 1625 nm for LEAF fiber. The higher power handling capability of new fibers such as LEAF fiber combined with an increase in usable bandwidth provided by the two amplifiers enables DWDM bandwidth to more than double.

The best option for system architecture clearly depends on the evaluation of costs, projected capacity requirements for a route, network reliability and other factors. In light of the ongoing quest for greater bandwidth, optical components designed to operate at longer wavelengths provide practical and economical solutions to service providers because they increase capacity, address the non-linear four-wave-mixing impairment and provide a "pay-as-you-grow" path for wavelength upgrades.

Finally, EDFA performance is largely determined by the performance of the internal componentry: isolator, tap, wavelength division multiplexer (WDM), filters and band splitters. What is needed, therefore, are components specified for the L-band. As service providers begin to fill the C-band, the additional capacity provided by L-band technology will be an essential part of many future DWDM systems. ▪

For more information
FROM *CORNING INCORPORATED*

For more information on Corning's PureGain™ EDFA modules call 800-525-2524 ext. 9092, or 607-786-8125 ext. 9092 outside the U.S. and Canada.

L-band erbium doped fiber amplifiers (EDFAs) can be designed for functionality and performance competitive with the most advanced C-band amplifiers. The design and architecture of L-band amplifiers is in fact quite similar to standard C-band amplifiers.

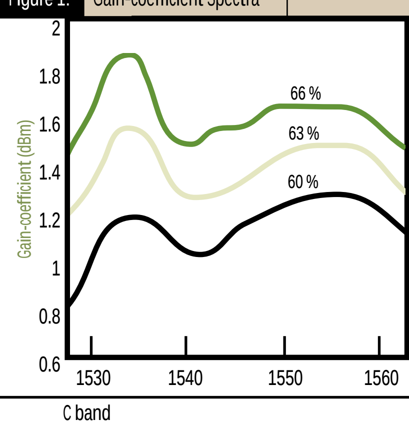
Current EDFAs operate in the conventional band (C-band) defined approximately as 1530 nm to 1562 nm, this wavelength range encompasses the erbium gain peak. The long-wavelength band (L-band) is defined approximately as 1570 nm to 1605 nm, this wavelength range encompasses only the tail of the erbium gain band. L-band EDFAs are distinguished by the comparatively long erbium coil lengths required for amplification. It should be noted that the range of both transmission windows can vary by several nanometers.

There are several basic technical issues related to the design and development of L-band EDFAs: (1) operating environment, (2) pump wavelengths, and (3) amplifier architecture and performance.

Operating Environment

The difference between C-band and L-band amplifier coil length is a direct result of the difference in operating environment. Amplifier gain (G) can be expressed as G = gc x L, where gc (dB/meter) is the gain coefficient and L (meter) is the erbium coil length. In the L-band, emission and absorption coefficients are three to four times smaller than the corresponding C-band values. In addition, L-band amplifiers operate at very low average inversion levels (40%)

Figure 1: Gain-coefficient Spectra



L-band Amplifier Design and Performance Parallels C-band EDFAs

in order to minimize the intrinsic gain ripple. The average amplifier inversion level defines the percentage of erbium ions that contribute to the amplification process. For reference, C-band amplifiers typically operate at 60% to 65% average inversion. Gain ripple is defined by the minimum and maximum amplifier gain as $[(G_{max}–G_{min}) / G_{min}]$ x 100%. The smaller emission and absorption coefficients along with the low average inversion cause the L-band gain coefficient to be significantly smaller than C-band (Figure1). The lower gain coefficient results in L-band amplifier (using standard Type-2 fiber) coil lengths that are four to five times longer than what is required for comparable C-band amplifiers. It is important to note, however, that the L-band gain ripple is an order of magnitude smaller than what is observed for C-band. The lower gain ripple means that L-band gain flattening filters (GFFs) are both easier to manufacture and produce less amplifier performance degradation (due to filter attenuation) than C-band GFFs.

Despite this advantage, the relatively longer L-band erbium coil length poses several fundamental challenges. First, the total passive fiber loss is higher; this decreases pump conversion efficiency (PCE) since both pump and signal powers experience greater attenuation. Pump conversion efficiency defines the pump power required to provide a given signal output power; thus, anytime pump photons are not used to amplify the signal, PCE is degraded. Pump power is often completely absorbed well before the output end of the erbium fiber. In these cases, signals encounter a net absorptive loss in the unpumped fiber region – this also reduces pump conversion efficiency.

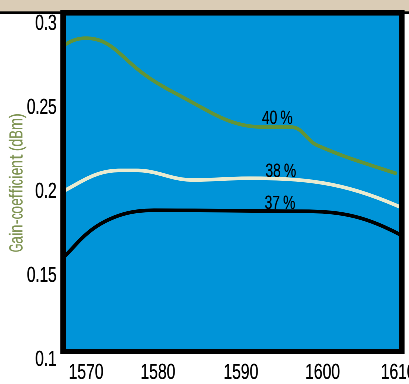
Next, the longer coil lengths result in substantial accumulation of backward amplified spontaneous emission (ASE) power. Again, PCE is degraded because pump photons are used to amplify backward ASE instead of being used to amplify signal power. Backward ASE also reduces inversion at the front-end of the amplifier; this increases noise figure. Hence, PCE (i.e., required pump power) and noise figure performance of L-band amplifiers is generally worse than what is observed for comparable C-band amplifiers.

Pump Wavelengths

The L-band operating environment also impacts pump wavelength options. In the C-band, PCE (λ_{pump}=980 nm) < PCE (λ_{pump}=1480 nm) because of the difference in photon energy conversion: $\lambda_{pump}/\lambda_{signal}$. The difference between PCE when λ_{pump}= 980 nm versus λ_{pump} = 1480 nm is even greater in the L-band. Since pump laser cost represents a substantial portion of the total amplifier cost, increasing pump conversion efficiency is a concern for commercial L-band amplifier development. One method to improve PCE in the L-band is pump wavelength tuning. The 980 nm PCE can be improved by several dB when the pump wavelength is tuned $\pm$ 25 nm away from the pump absorption peak at 980 nm. Pump wavelength tuning is also an option for 1480-nm pumped L-band amplifiers. Because of the low inversion operating environment, the L-band can be pumped efficiently at wavelengths as high as 1550 nm. This result is significant because it creates the possibility of ASE pumping, wherein backward ASE (peaked near 1532 nm) can be employed as pump power. ASE pumping is the effective reuse of pump power that has been converted into ASE power. A second possibility is the use of fiber lasers as high power pumps for the L-band amplifier. Thus, the L-band offers some rather novel options for pump wavelength and pump configuration.

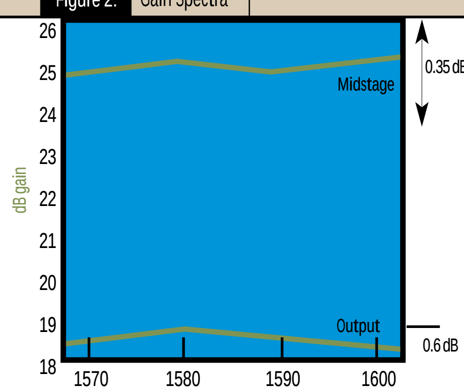
Amplifier Architecture

Figure 2 shows the block diagram of a Corning L-band amplifier prototype that was demonstrated in February at OFC'99. The amplifier gain spectrum in the Corning L-band amplifier prototype is flattened at the midstage (to allow midstage access) and at the output; also, signals are monitored at all access points (Figure 3). This L-band amplifier has 1.4% gain ripple (i.e. 0.35 db ripple per 25 db gain), which is smaller than typical C-band gain ripple (4% to 6%). Noise figure is approximately 1.0 dB greater than typical C-band values and PCE is approximately 2.0 dB worse than in the C-band. The initial amplifier stage is pumped with λ_{pump} = 980 nm in order to achieve high front-end inversion; the final amplification stage is pump with λ_{pump}=1480 nm in order to exploit the higher PCE associated with this pump wavelength band. This is the same pumping paradigm that is used in C-band amplifiers. As indicated here, much of Corning design and manufacturing knowledge gained from the production of C-band amplifiers can be applied directly to L-band EDFAs. The development of L-band EDFAs is proceeding at an aggressive pace; it is expected that these next generation amplifiers will have a significant impact on lightwave systems in the near future. ■



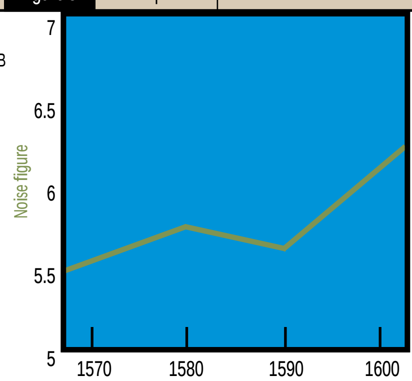
L band

Figure 2: Gain Spectra



Wavelength (nm)

Figure 3: Noise Spectra



Wavelength (nm)

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