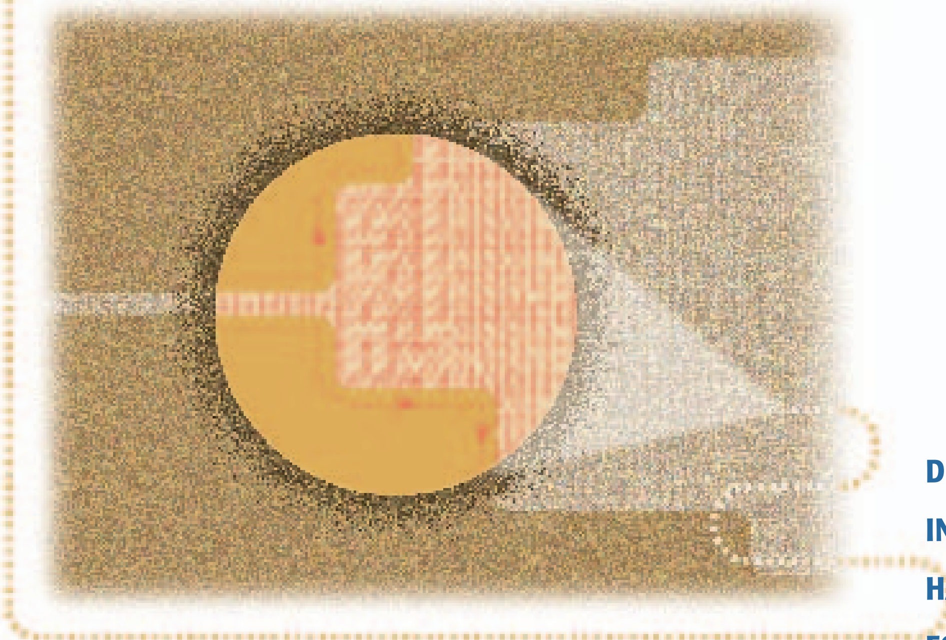
 By Joshua Israelsohn, Technical Editor



Fiber lights the SHORT HAUL

DESPITE EXCESS CAPACITY IN THE LONG HAUL, THESE HAVE BEEN DARK DAYS FOR TELECOMM- AND DATACOMM-EQUIPMENT VENDORS. BUT INNOVATIVE FIBER-OPTIC TECHNOLOGIES FOR SHORT-HAUL APPLICATIONS ARE BREAKING MULTIPLE BOTTLENECKS AND LIGHTING THE WAY TO GREATER CHANNEL DENSITIES AND A BRIGHTER OUTLOOK.

As equipment manufacturers and network operators have refocused their attention from long-haul networks to MAN (metropolitan-area-network) and access technologies, component vendors have observed a convenient confluence of requirements from the telecomm and datacomm segments. This shift has occurred despite the fact that these two segments traditionally have distinguished themselves with different channel-performance requirements.

Since the end of 1998 when data traffic outstripped voice, COs (central offices) have required increasingly large numbers of short-haul links to route deaggregated traffic through switching equipment (**Figure 1**). The I/O transceivers servicing those links must take a minimum of board-edge space, dissipate little power, and carry signals over the OC-3 to OC-192 range. They also must offer low signal attenuation and low distortion. These requirements, particularly in the regions of 2.5 and 10 Gbps, align nicely with those from the datacomm segment, which is looking beyond the throughputs afforded by 1- and 2-Gbps links for SANs (storage-area networks) and LAN (local-area-network) backbones (**references 1**, **2**, and **3**). This alignment of performance requirements is causing a peak in demand for fiber-optic short-haul and VSR (very-short-reach) transceivers. It is also causing some transceiver vendors to push into the MAN from the short-haul side to fill the gap for intermediate-reach links (**Figure 2**).

Though fiber-optic devices for long-haul services continue to evolve, fiber's push into LAN and SAN applications

Illustration by Daniel Guidera

has not derived from incremental advances in long-haul technologies. On the contrary, to capture the cost-sensitive datacomm market, fiber-optic-interface technologies depart significantly from those for long haul and even from earlier generation short-reach devices. Low-cost, low-power, small-footprint fiber-optic I/O derives largely from advances in semiconductor processing and in electronic and fiber-optic assembly and packaging (**references 4** and **5**).

A LIGHT, HIGH-FIBER DIET

Many short-haul links carry aggregated payloads in the few tens of gigabits per second. Others carry multiple, lower rate, independent feeds. Both can take advantage of comparatively inexpensive VCSEL (vertical-cavity-surface-emitting-laser)-diode-based transceivers and MMFs (multimode fibers). The lower base cost of fiber is only one source of savings. MMF has a less stringent alignment requirement than SMF (single-mode fiber), which allows installers to terminate the fiber in the field (**Reference 6**). This ability lowers the installation cost and increases the flexibility of the network configuration, which protects the end customer's investment. MMF also provides a lower price point for multifiber-ribbon assemblies, which themselves reduce installation costs by providing more traffic capacity per cable pull.

On the transmission end, VCSEL-based transceivers are less expensive than Fabry Perot or DFB (distributed-feedback) edge-emitting lasers. They require less silicon area and allow fabricators to test the devices while they are still in wafer form. They also use common semiconductor-industry process steps for wafer dicing and die handling.

As planar devices, VCSELs produce a beam geometry that couples energy into the fiber more efficiently than do edge emitters (**Figure 3**). Older 850-nm VCSELs are well-established in data-communications applications. More recent 1310-nm devices appeal to the telecommunications market, which uses the

AT A GLANCE

▷ Converging short-haul telecomm and datacomm fiber-optic-link requirements make a demand peak at data rates of 10 to 40 Gbps for links from a fraction of a meter to a few kilometers.

▷ VCSEL arrays have enabled fiber-optic-module makers to greatly increase port density per unit length of board edge. Standard electrical and optical interfaces enable interoperability or interchangeability between vendors' modules.

▷ Eye-safety specifications have evolved. Requirements from different standards and regulatory organizations have largely converged.

PLAYING IT SAFE

If you're not familiar with eye-safety measures and procedures regarding fiber-optic transmitters, you should be before you start to work with them. Module makers go to considerable lengths to comply with established standards. However, if you don't know what the standards specify and under what conditions, the phrase "eye safe" can lose its meaning.

IEC (International Electrotechnical Commission) 60825-1 specifies laser classifications, exposure levels and times, and tests (**Reference A**). Of the laser classifications that IEC 60825-1 defines, two are most commonly associated with fiber-optic transmitter modules for short-haul service. Class 1 lasers are unconditionally safe, including cases in which you view them with instruments. Class 1M lasers are safe when you view them without instruments (**Reference B**). Both classifications assume that the modules are running within their specified operating conditions.

The International Committee on Nonionizing Radiation Exposures has defined biologically safe exposure limits from which IEC 60825-1 derives MPEs (maximum permissible exposures). The MPEs, in turn, form the basis for calculating the AEL (accessible emission limits) for a given laser class and wavelength at an exposure duration of 100 sec. The calculated AELs essentially place an upper bound on the transmitter's output power, depending on which safety class the manufacturer is targeting.

Your eyes are more sensitive to short-wavelength radiation than to long. So, in addition to getting better fiber attenuation and dispersion performance, transmitters output more power from a 1300-nm VCSEL than an 850-nm device within a given eye-safety classification.

The most recent amendment to IEC 60825-1, which the IEC added last year, uses new MPEs and larger resulting AELs that increase the Class 1 power for 840-nm devices on 50-mm MMF to −1.24 dBm: 2.46 dB, or nearly a factor of two, over previous limits. The same device operating to Class 1M has an AEL of 9.43 dBm—nearly a factor of 12 over previous Class 1 limits. These changes allow additional transmit power, which in turn reduces the demand on receiver sensitivity. But your eyes haven't changed, so the other result is that the safety margin a given class offers is now smaller.

Suppliers and customers of components, modules, and equipment are scattered across the globe. It does little good to have one standard in force in the European Union, another in the Americas, and yet a third in, say, Japan. The need to converge, or "harmonize," standards from disparate geographical regions and governing bodies is a familiar one. In this case, the job may be easier by virtue of an unusually close association. IEC Technical Committee 76 was responsible for amending 60825-1. Its chairman is also a key laser safety official at the US-FDA (Food and Drug Administration). The FDA Center for Devices and Radiological Health's Standard 21 CFR (Code of Federal Regulations) 1040 is the regulatory document in the United States that most closely corresponds to IEC 60825. ANSI (American National Standards Institute) standard Z136 covers safe use of lasers.

You can purchase a consolidated version of 60825-1, which includes the two amendments currently in force, for about $100 directly from the IEC. A combined set of Z136.1 and Z136.2, "Safe Use of Lasers" and "Safe Use of Optical Fiber Communications," is available from ANSI for $144. Additional transmitter-specific safety information is available from the IEEE, SPIE, and from module vendors.

REFERENCES

A. "Safety of laser products, Part 1: Equipment classification, requirements and user's guide," IEC, 2002.

B. Kolesar, Paul and Jane Ehrgott, "Laser safety standards update and impact on 850 nm serial PMD," Lucent Technologies, presented at IEEE 802ae Albuquerque, March 2000.

longer wavelength because it better matches the attenuation and dispersion characteristics of the fiber.

The basic architecture of a fiber-optic transceiver is similar to that of copper transceivers. In the fiber-optic module, however, laser-diode emitters and modulator/drivers take the place of cable drivers. Similarly, PIN-diode detectors and limiting amplifiers take the place of the cable receivers (**Figure 4**). Emitter and detector manufacturers form VCSELs and PIN diodes in III/V processes, increasingly InP (indium-phosphide). They usually make modulator/drivers and limiting amplifiers in either a III/V process or in SiGe (silicon-germanium) due to the bandwidth demands on those circuits. CMOS offers greater integration but lower bandwidth, which suits the parallel system interface's requirements.

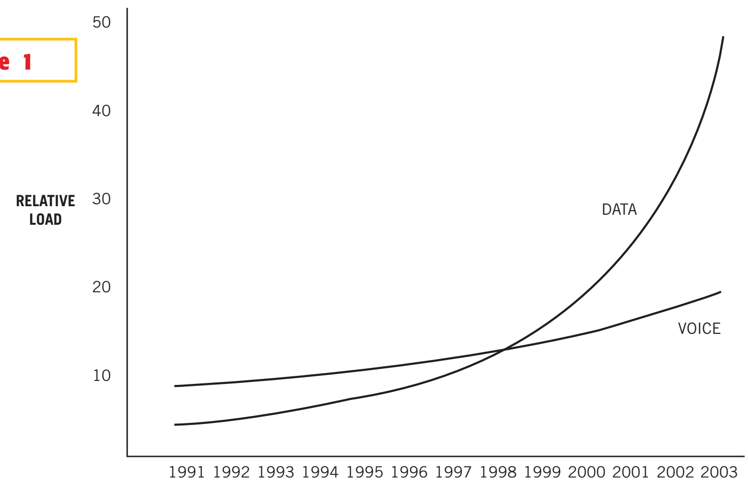
How best to implement the various signal-processing functions is a subject that attracts differing opinions. Vendors in favor of integrating more in III/V favor a two-stage multiplexer-and-demultiplexer topology. This arrangement uses III/V circuits for the high-speed portion of the signal chain from the fiber interface to a 4-to-1 multiplexer and 1-to-4 demultiplexer. These blocks connect to a system-side chip that provides all the functions from the 16-to-4 multiplexer and 4-to-16 demultiplexer to the system-side interface, built in vanilla CMOS. Vendors using SiGe prefer single-stage multiplexers and demultiplexers, which allow them to process the signal from the system interface to the serial stream in a single technology. Proponents of the two-stage topology claim that it allows for standardized components based on a unified method of segmenting the module and a smooth evolution to OC-768. Proponents of the single-stage architecture claim that it allows for greater integration and lower cost. The merits of these arguments are in flux, as are the fabrication technologies involved. On the one hand, the practical limits of integration in III/V processes continue to recede, though in no way like silicon processes. Meanwhile, SiGe speeds are surpassing the expectations of most industry watchers. A case in point is IBM's recent announcement of its SiGe 8HP process, which has yielded circuits operating faster than 100 GHz.

End users may care little about the infighting between component manufacturers except for the fact that it divides the market those vendors serve and reduces the economies-of-scale benefits they realize in the module market. Depending on the application, short-haul fiber-optic transceivers may support a variety of channels, including Ethernet, Fibre Channel, InfiniBand, and SONET (synchronous optical network). These standards impose different demands on the physical layer. SONET, for example, is most demanding of jitter performance. But module makers have found that they can meet the requirements of different standards with more unified design strategies than was practical in earlier generations. Part of this trend is due to the fact that the services are placing similar bandwidth demands on the media and, thus, on the transceivers, allowing module designers to contemplate more "protocol-agnostic" designs.

With port-density demands ever on the rise and newer generation fiber-optic transceivers dissipating less power, the fiber termination becomes a key limiting factor to the number of channels you can fit onto a card edge. Advances in packaging and fiber-termination technologies have given rise to multifiber-I/O modules. These modules not only greatly increase I/O-port density, but also allow end customers to connect links carrying many tens of gigabits per second with one fiber-optic ribbon cable.

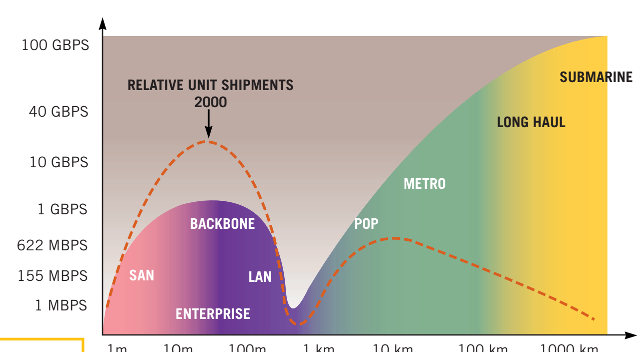
Gore's nL120x parallel fiber-optic modules exemplify this architecture (**Figure 5**). The nL120x family includes transmitters and receivers operating 12 channels each at either 1.25 or 1.6 Gbps, depending on the model. The transmitters use 850-nm VCSELs for the optical interface and LVDS (low-voltage differential switching) for the elec-

Figure 1



Since the forth quarter of 1998, public networks have carried more data than voice. As the data traffic growth rate accelerates, central offices require ever-denser low-power I/O for short-haul routing (courtesy Biswanath Mukherjee, University of California–Davis).

Figure 2



Common requirements of short-haul telecomm and higher speed datacomm links create a peak in the market demand for fiber-optic transceivers in the 10- to 40-Gbps region. Meanwhile, module makers see an opportunity to extend short-haul technologies to open bottlenecks in the single-digit-kilometer range and in board-to-board links (courtesy PicoLight).

trical interface. The nL1201-1.6 transmitter and nL1202-1.6 receiver operate on either end of standard FDDI (fiber-distributed-data-interface)-grade, 62.5/125-micron, graded-index, multimode ribbon fiber as long as 300m.

Typical of this type of module, the nL120x offers a maximum channel bit-error rate of 10^{-12} for compatible transmitters and receivers. The nL1201-1.6 transmitter dissipates a maximum of 1.5W from a 3.3V nominal supply to develop an average launch power of −10 to −14 dBm. Maximum jitter is 190 psec, and typical channel-to-channel skew is 150 psec. The 1.6-Gbps nL1200 series modules, which offer a 19.2-Gbps aggregate data rate in less than 20 mm of board edge, cost as little as $650 (high volumes).

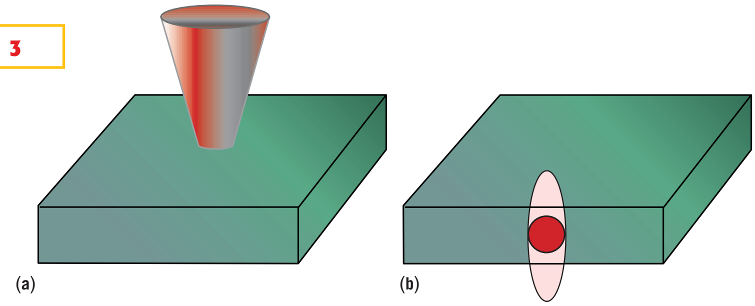
Zarlink offers a 12-channel, frequency-agile VSR transmitter/receiver pair, the MFT62340A-J and MFR62340A-J, respectively. These 3.3V modules provide differential current-mode-logic electrical interfaces. Like many other available transmitters, the MFT62340A-J uses an 850-nm VCSEL array. The 623's individual channels can independently operate at data rates of 155 Mbps (OC-3) to 2.5 Gbps (OC-48).

As you would expect, the maximum link length is a function of the maximum data rate, but the relationship is nonlinear. At their slowest rate, a 623 module pair can operate through an 800m multimode ribbon; at the fastest rate, that range drops to 100m. Between the two, at 1.25 Gbps, the range is 200m. Transmitter/receiver pairs cost $1100 (low volumes).

Perhaps the biggest boon to short-haul fiber optics is the connectorized transceiver module (**Figure 6**). Equipment manufacturers don't want high-density I/O cards with many thousands of dollars worth of fiber-optic transceivers in their finished-goods inventory. Such an arrangement is not only expensive, but also inflexible. It prevents the manufacturer from configuring a board after assembly for channel counts or speeds, which adds even more inventory cost. Soldered transceivers can also raise the equipment-acquisition cost to the end user by making a coarse-grained I/O channel.

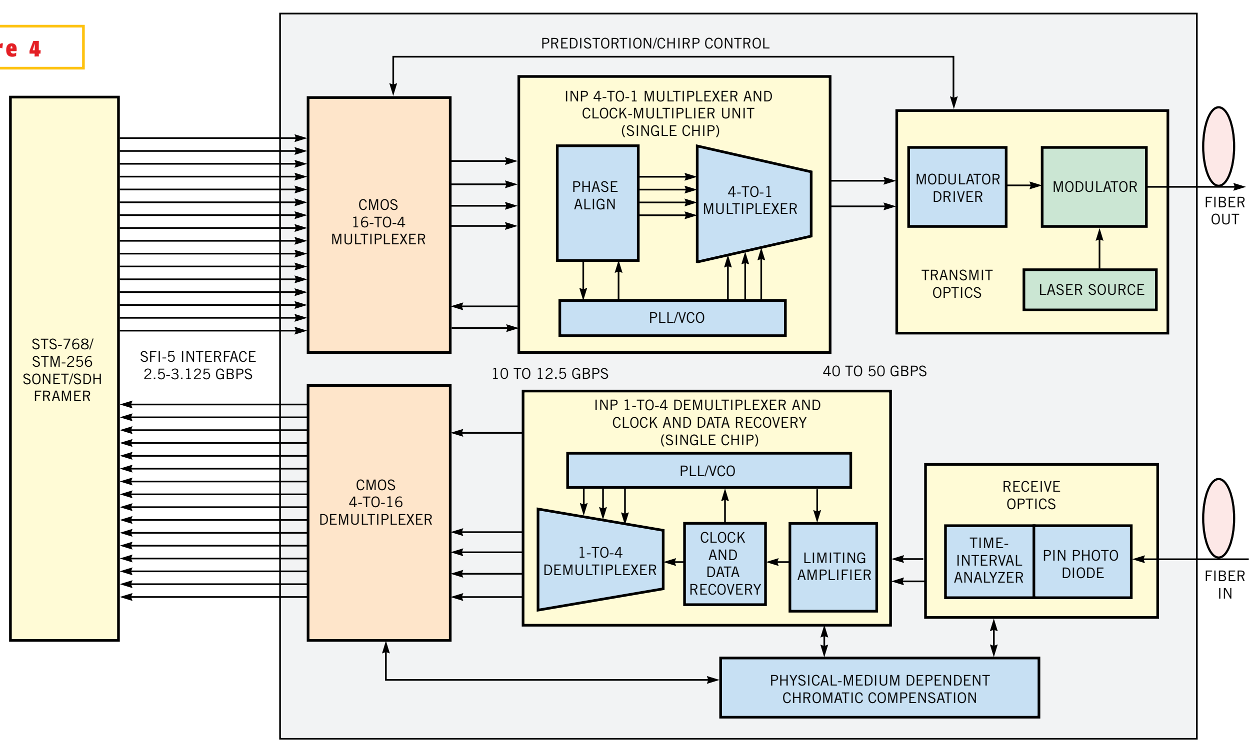
Connectorized BGA/LGA (ball-grid-array/land-grid-array) modules solve this problem by allowing manufacturers to "provision" the fiber-optic I/O to order. The I/O connectors also allow manufacturers to test boards before committing expensive transceivers to them, which can reduce the yielded cost of the finished

Figure 3



As planar emitters, VCSELs (a) produce a circular beam that couples more efficiently into an optical fiber than does the elliptical beam edge-emitting Fabry Perot or distributed-feedback lasers (b) produce (based on information from Cielo).

Figure 4



With the exception of media-specific drivers and receivers, the topology of a fiber-optic transceiver is similar to that of its counterpart for copper media (based on information from Inphi).

boards. Boards with connectorized I/O also give users the flexibility of expanding their systems while protecting their base investment. A network-equipment customer might, for example, purchase a 16-module board with only four modules in place. As the network expands, the customer may purchase additional modules and install them in the field.

PicoLight was one of the first module makers to offer connectorized multifiber modules. The company's Magnus family includes the PL-TCP-00-Sxx series of 12-fiber transmitters based on 850-nm VCSEL arrays and the PL-RCP-00-Sxx family of mating receivers. Individual models operate with data rates to 1.6, 2.5, or 2.7 Gbps for an aggregate bandwidth as high as 32 Gbps in less than an inch of board-edge space. The module's footprint is only twice that of industry-standard small-form-factor modules that operate single 1-Gbps strands. The 12 channels operate asynchronously for VSR rack-to-rack and switch-to-switch connections.

The Magnus modules use a standard MTP optical interface with 50/125- or 62.5/125-micron multimode fiber. Their operating range is either 300 or 600m, depending on the type of fiber you use. The parallel optical interconnect complies with IEEE 802.3 1000-BaseSX. A 12-channel transmitter/receiver pair dissipates 2W. Prices for the 2.7-Gbps modules start at $1500 (low OEM volumes).

PicoLight's first foray into long-wavelength is the 1310-nm PL-XPL-00-L13 pluggable transceiver modules for links as long as 20 km. The SFP (small-form-factor-pluggable) transceiver operates at 1.06 or 1.25 Gbps for Gigabit Ethernet 1000BaseLX and Fibre Channel 100-SM-LC-L service over SMF. The $150 (1000) module is the first in PicoLight's Extensus family, which targets low-cost point-to-point applications, such as EFM (Ethernet in the first mile).

Cielo also offers both 850- and 1310-nm VCSEL-array based modules. Last fall, the company demonstrated that its 850-nm modules interoperate with PicoLight's in links as long as 450m using MMF from a variety of sources, including Corning, Lucent, and CDT, with an error rate lower than 10^{-12}. Provable interoperability at the module level is a large concern for equipment makers. It is also a key concern for end users who expect some assurance that equipment they buy to expand their networks will work properly with the existing equipment base.

In the 1310-nm wavelength, Cielo offers eight- and 12-channel pluggable transmitter and receiver modules targeting high-density OC-48 and backplane applications. Like the PicoLight multifiber modules, Cielo's channels are mutually asynchronous. They are frequency-agile from OC-3 to OC-48 and dissipate a mere 0.25W per channel The modules cost less than $600 per channel in sample quantities and support links as long as 15 km.

The Xenpak MSA (multisource agreement) is boosting 10-Gbps Ethernet. The agreement defines 850-nm serial, 1310-nm serial, 1310-nm WWDM (wide-wavelength-division-multiplexing), and 1550-nm serial pluggable transceivers. Agilent's 10 GbaseLR Xenpak transceiver provides an XAUI (10-Gigabit attachment-unit-interface) electrical interface and meets the proposed IEEE 802.3ae 10-Gbps Ethernet standard. The uncooled, directly modulated, 1310-nm serial transceiver has a range of 10 km. Agilent's transceiver includes a complete physical layer from the fiber to the four-channel, 3.125-Gbps XAUI interface, including both 8B/10B and 64B/66B encoding and decoding. The hot-pluggable modules cost $1000 (high volumes).

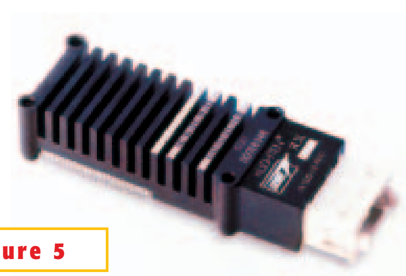


Figure 5

Gore's nL120x modules typify the design for 12-channel transmitters and receivers.

Blaze Network Products supports the Xenpak MSA with its FT-XGLX-02. Unlike Agilent's Xenpak transceiver, Blaze's module uses 1310-nm CWDM (coarse-wavelength-division-multiplexing) DFB lasers. The transceiver operates over 10-km links on SMF and 300m through MMF, which allows end users to employ existing fiber runs. Blaze's 10GBbaseLX4 Xenpak-compatible transceiver costs $1600 (moderate volumes).

Other module suppliers that have signed on to the Xenpak MSA include Agere, Mitsubishi Electric, Pine Photonics Communications, Optillion, and Tyco. IBM has announced that it will also support the Xenpak MSA.

For those who don't need to drive SMF, Blaze also supports 10-Gbps Ethernet, OC-192, and 10-Gbps FC (Fibre Channel) with CWDM transceivers built around 850-nm Emcore VCSEL arrays. The four oxide VCSELs emit at 778, 800, 825, and 850 nm over an operating temperature range of 0 to 90°C. Blaze's AB-XGSX-01 transceiver can drive 100m of 62.5/125-micron MMF or 300m of 50/125-micron MMF at 2.488 Gbps and costs $500 (high volumes). The transceiver can operate to 3.1875 Gbps on 20% shorter runs.

VCSELs solve a large part of the fiber-alignment problem of parallel-fiber I/O. Fabricators form the emitters and their corresponding PIN-diode detectors in regular arrays whose element-to-element positional tolerance is limited only by the semiconductor photolithography process. The benefit of this approach increases as arrays grow larger, which has motivated some module makers to consider 2-D array structures.

One of these manufacturers, TeraConnect, offers 48-channel pluggable transmitters and receivers that it builds on 4×12-element VCSEL and PIN arrays. The TC-T-48T-250Na transmitter and the TC-T-48R-250Na receiver combine for an aggregate data rate of 120 Gbps over 300m runs. Individual channels can operate mutually asynchronously. The transmitter/receiver pair fit within 6-in.^{2}-board-space and 8W-power budgets.

The 48T uses dc-coupled current-mode logic for the channel electrical interfaces. On-chip 50Ω termination resistors simplify the layout. Control signals use LVTTL (low-voltage transistor-to-transistor-logic). TeraConnect forms the optical interface through a pair of 2×12-element MT, ferrule-based connectors using 62.5/125/250-micron, 12-element fiber ribbon. Power-management circuits independently control each row of 12 channels for instant power-up and -down. I/O designers can adjust the laser driver bias and modulation currents over a slightly greater than 2-to-1 range in 14% increments to compensate for temperature and aging effects. The transmitter meets the eye-safety requirements of ANSI Z136.2, IEC 60825 for classification 3A and FDA Class 3 (see **sidebar** "Playing it safe"). The T48 modules cost less than $1200 (production volumes).

Needless to say, the appeal of arrayed structures doesn't end at 4×12 elements. TeraConnect has demonstrated 16×20-element VCSEL and PIN-detector arrays mounted in single 640-fiber transceiver modules. The fully synchronous modules communicated over a 36m fiber-optic bus at 133 Mbps per channel with a bit-error rate of only 10^{-15}. Although a single demonstration proves neither the practical limits of the technology nor the market need for massively parallel structures, it marks a noteworthy milestone along the fast-paced evolutionary path of fiber-optic I/O.

CAVEAT SPECIFIER

Beyond safety, fiber-optic module specifiers need to remember a couple of other issues as they develop their designs. Interoperability among modules of similar capability is not a given. Module vendors have been busy demonstrating and documenting the interoperability of their wares with each other at trade-show exhibitions as well as in more traditional applications development labs. Check which modules your design needs to be compatible with before choosing a particular model for your design.

Figure 6

PicoLight's pluggable modules help solve inventory and configuration problems for I/O-board makers and provide end customers an inexpensive upgrade path that protects their basic technological investment.

Modules that interoperate are not necessarily interchangeable in your design. For interchangeability, look at which modules share an MSA. MSAs cover, at a minimum, the module's physical dimensions, the mounting mechanisms, pin out, fiber-optic connector, and key operating specifications. Familiarize yourself with the text of the MSA to see what specifications it covers. Ironically, while MSAs ensure mechanical and electrical interchangeability, they do not guarantee equivalent performance. Indeed, some MSAs cover multiple mutually incompatible optical interfaces. A careful analysis of the MSA specifications and those parameters that the drawing omits helps you identify which modules will work with your design.

Though fiber-optic cables present no EMI-radiation problem, the electrical end of a fiber-optic module can radiate. In this regard, not all modules are created equal. Some include EMI collars that engage the perimeter of your panel cutout. Some module packages inherently provide better self-shielding. As modules get smaller and packing densities get tighter, low-crosstalk pc-board layout becomes more challenging.

Compared with the pure electronic-component manufacturers with which you are familiar, fiber-optic-module vendors play their cards much closer to their vests. Although this trait is within their rights, it means that you need to allow sufficient extra time in your design cycle to gather basic information. For example, most vendors do not make public their full data sheets. You may need to sign a nondisclosure agreement to get a peek. If so, getting nondisclosure-agreement approval within your own organization will take far more time than the usual half-dozen clicks to download a spec sheet from a component vendor's Web site. Vendors often similarly guard pricing information. Several vendors even omit

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part numbers in their publicly disclosed information.

Other vendors recognize that a requirement for a nondisclosure agreement from every potential customer can slow the wheels of commerce and opt for posting their data sheets on a password-protected section of their Web sites. Typically, you apply for a password through an online form, which then goes to a human checker who authorizes a password. Several vendors using this method claim that they make passwords available within 24 hours, but Murphy's Law suggests that you prepare for a longer delay.

Last, it takes a long list of specifications to describe a fiber-optic module. Many of these specs are peculiar to this type of product. Your design performance doesn't depend on just one module; the combined performance of the transmitter/receiver pair is what matters. This complexity makes comparisons among competing modules difficult. Ironically, it may be easier to compare relatively sophisticated measures, such as jitter performance, than the more mundane module characteristics. In this example, your jitter spec derives from the communications standard you are using. Assuming that you've followed the manufacturer's layout recommendation, a module's native performance is either good enough or not. But the communications standard doesn't determine how much power your design dissipates, how densely you pack your I/O ports, or what link lengths you support. Those items are subject to a trade-off analysis in your design, assuming that you and your product-line management have some guiding principle to help assess the value of various trades.

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PicoLight chief executive officer Stan Swirhun suggests that a useful collective metric for fiber-optic modules combines the aggregate speed in gigabits per second, board-edge space in inches, power dissipation in watts, and fiber-run length in meters. Although compound metrics such as these are not industry-standard, they appear useful in applications that place a premium value on high port density and low operating costs.□

ACKNOWLEDGMENT

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REFERENCES

1. Mukherjee, Biswanath, "WDM optical communication networks: progress and challenges," *IEEE Journal on Selected Areas in Communications*, October 2000, Volume 18, No. 10, pg 1810.

2. Swirhun, Stan, presentation to the Optical Portfolio Conference, Oct 25, 2001.

3. Himes, Diane, editor, "10 Gigabit Ethernet: the road to standardization," *Fiberoptic Product News*, January 2002.

4. Israelsohn, Joshua, "Packaging solves 'the last centimeter'," *EDN*, May 24, 2001, pg 73.

5. Israelsohn, Joshua, "Ripples in the process pool," *EDN*, Jan 24, 2002, pg 44.

6. Blaze Network Products, "Fiber Options," white paper, 2001.