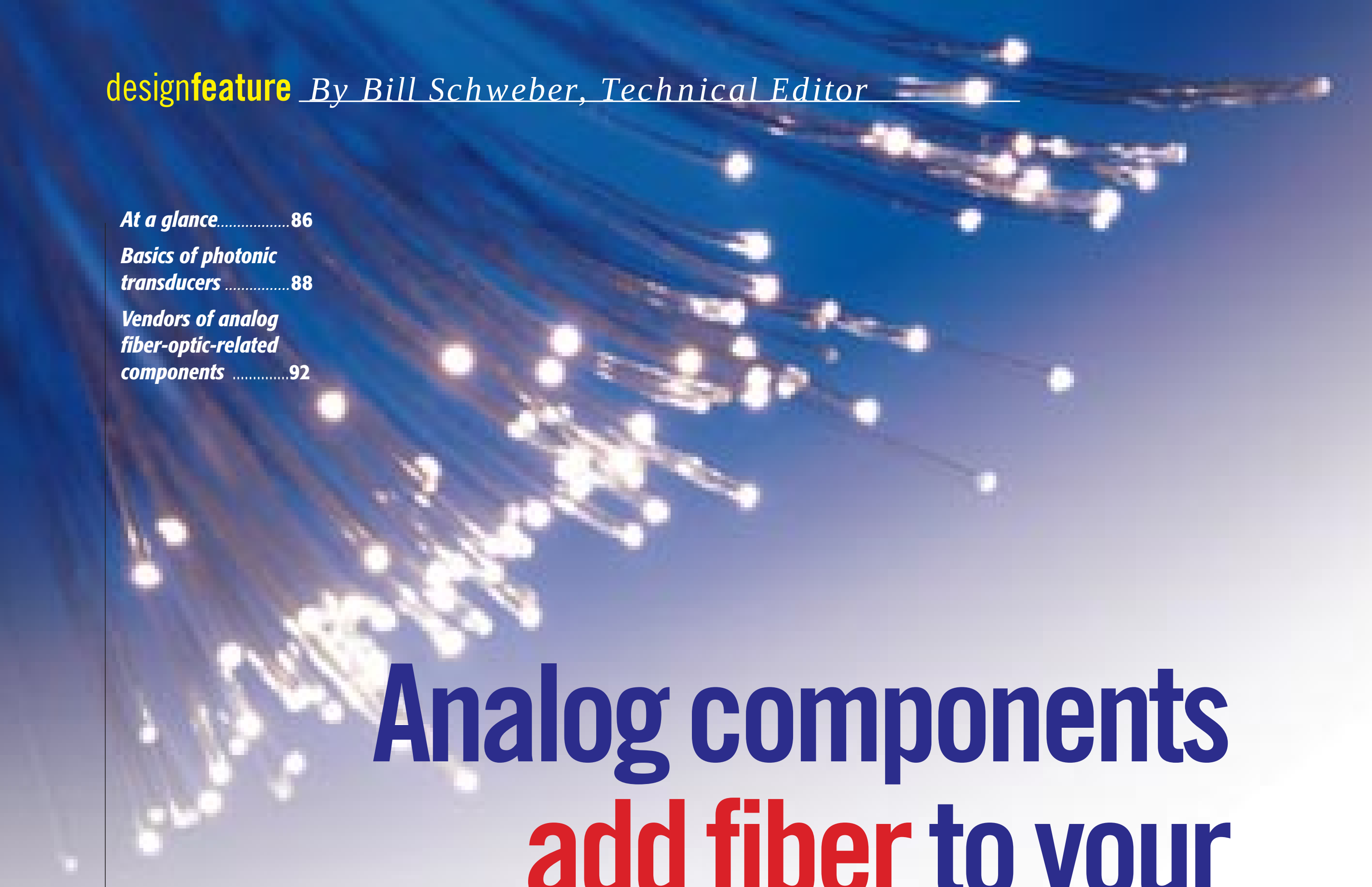
By Bill Schweber, Technical Editor



Analog components add fiber to your communications diet

TO EFFECTIVELY INTERFACE BETWEEN THE DIGITAL ELECTRONIC WORLD AND THE OPTICAL WORLD, YOU NEED TO USE ANALOG COMPONENTS DESIGNED TO ACCOMMODATE THE UNIQUE CHARACTERISTICS OF ELECTRO-OPTICAL COMPONENTS.

Optical fiber is the near-perfect communications medium in so many ways. It has virtually infinite bandwidth, it's immune to the ravages of EMI/RFI, it does not source EMI/RFI, it has low loss, it's lightweight, and it's reasonably priced—to call out just a few of its virtues.

But there's a problem with using optical fiber: Because all of the associated circuitry is electronic, you need to incorporate electro-optical components to straddle the chasm between conventional electron-based systems and the fiber's photon-based world. And along with these bridges—LEDs and lasers as well as photodiodes and other detectors—you need the right electronic components to serve as transitions to these electro-optical components. The electro-optical components have some characteristics that are unlike those you encounter in many other electronic components.

Fortunately, the virtues of fiber optics and society's relentless need for more bandwidth mean that vendors have the incentive to provide both the necessary interface ICs and the basic electro-optical transducers. Ironically, between the all-digital world on the data-source side and the corresponding digital world on the receiver side, the communications link has several key functions that you must implement with analog circuitry (**Figure 1**).

SOURCE AND RECEIVER DIFFER RADICALLY

Because the photon source and photon receptor differ significantly from each other, so does their requisite interface circuitry and the design considerations on each side (see **sidebar** "Basics of photonic transducers"). You can use the ubiquitous LED for data rates as high as about 50 to 100 Mbps. LEDs are easy to drive with a pulse waveform and tolerate brief overcurrent situations.

As your data rates increase beyond 100 Mbps to 155- and 622-Mbps SONET/SDH (synchronous-optical-network/synchronous-digital-hierarchy) rates, the LED is too slow, and you need a laser diode or a variation called the "vertical-cavity surface-emitting laser" as your light source. The good news is that the laser diode is a relatively efficient and fast source; the bad news is that it is finicky and has some idiosyncratic operational characteristics that your drive circuitry must take into account. Unlike most electronic components, the laser diode ages. Its power output declines, and its operating thresholds shift with time and use. Therefore, you need to continuously monitor its performance.

This aging alone is annoying but not fatal. But you also have to accommodate the laser diode's sensitivity to temperature. Therefore, you need some sort of closed-loop control to stabilize and maintain average output power and to appropriately adjust the operating bias level so you can properly modulate the diode. For this reason, laser diodes include a monitor photodiode in their structure, so control circuitry can monitor the lasers' output power and adjust the bias voltage as needed as part of automatic power control

AT A GLANCE

▷Effective use of fiber-optic transmitters requires that you match the analog drive circuitry to the subtleties of the photon source and match the analog receiving circuitry to the characteristics of the photon receiver.

▷Operation at 3V saves some power but also presents severe challenges in head room at the transmitter end and in noise and dynamic range at the receiver end.

▷To minimize your time to successful project completion as well as any unpleasant surprises, work with IC vendors to obtain reference designs and electrical, mechanical, and thermal models when you are working with data rates of 622 Mbps and faster.

(APC). Driver-IC vendors often characterize a family of laser diodes then tailor the driver to match the measured parameters.

Along with maintaining power-output level, your laser-diode drive circuitry must work at high speed from relatively low supply voltages yet source fast-slewing currents of 30 to 60 mA at high speed. The trend from 5V supplies to supplies as low as 3 to 3.6V significantly aggravates the problem, yielding a severe drive challenge.

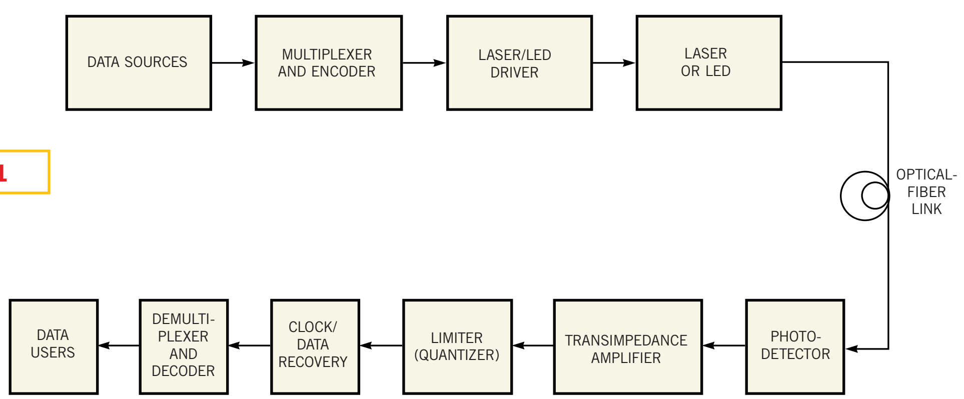
A quick run through the numbers shows the specifics of this challenge. Consider even 10 unavoidable nanohenries of package-lead inductance, coupled with a maximum rise time of just several hundred picoseconds (for gigabit Ethernet systems) and with a drive current of 30 mA. Your requirement is a positive voltage swing of 750 to 1000 mV. The falling edge of the data pulse needs the same swing in the opposite direction. Therefore, the overall drive-voltage swing ranges from 1.5 to 2V. To this value you must add the forward voltage of the laser diode (1.3 to 2V), so the total swing needed is 3V or more—difficult to achieve from a 3 to 3.6V supply.

You also need to consider the "extinction ratio," which is the power level for a data one divided by the power level for a data zero. Because the diode is not completely turned off for a zero, it has some small photon output at all times. If the extinction ratio becomes too small, the output-power levels of the diode has insufficient separation between the diode's two data states, increasing the likelihood of bit errors at the receiver. Again, the temperature sensitivity of the laser diode makes maintaining the ratio in the desired span difficult. For example, as the ambient temperature goes from 25 to 50°C, the current that the diode requires for full nominal output may increase from 10 to 30 mA.

It's not enough to drive the laser diode with a current that rises and falls sharply and that has enough swing despite limited supply-rail head room. You also have to control the slewing profile of the current so that you have a well-behaved drive signal to the diode, with minimal overshoot, ringing, and jitter—all of which can cause the receiver to increase its probability of error.

Finally, there's a laser-diode consideration that is unusual in low-voltage circuits: operator safety. The optical output of laser diodes, especially those that operate in the 780- to 850-nm short-wave window, can

Figure 1



The electronic/fiber/electronic signal chain links data encoders; a photon source and drivers; a photon receiver; a transimpedance amplifier; a signal limiter (quantizer); and clock-recovery, data-retiming, and signal-regeneration functions.

cause permanent eye damage. The APC circuitry limits the output power, acting as a major safety mechanism, but it's not enough in many applications. If any single fault in the APC function, such as a short to supply or ground, results in an out-of-control APC, user safety is at risk. The drive circuitry and APC should tolerate any such fault; in many applications, it is also important that the circuitry report the fault condition.

Beyond steady-state operation, your drive circuitry has to take into account inevitable transient and start-up conditions. If the laser-drive circuitry comes on before the APC loop is fully closed and operational, the circuitry may momentarily produce an excessive output-drive level, which in turn could damage the laser diode.

RECEIVING IS ANOTHER WORLD

Though source-drive circuitry and the type of photon transducer you use vary, all receiver circuits are conceptually similar—and very different from the source-end circuitry. Part of this dissimilarity stems from the fact that the physical structure of the source transducer differs from that of the receiver transducer, but some of the gap stems from the fact that the receiver and the source face unique challenges. Transmitting takes a known, relatively strong signal and adapts it to the photon source. In contrast, receiving requires you to capture and extract an unknown data signal with just approximately known parameters and then re-create the original data stream from this recovered signal. The receiver's technical issues involve sensitivity to low-level signals, which are characterized by input-referenced noise, gain, and bandwidth; dynamic range and immunity to overload from

BASICS OF PHOTONIC TRANSDUCERS

As electrically driven photon sources, LEDs and laser diodes differ significantly in construction, operation, and characteristics. An LED's output is nearly linear with applied drive current, and LEDs are easy to modulate with on/off currents.

In contrast, a laser diode has a threshold current-drive requirement. Below this threshold, lasing action does not occur; above this value, the diode produces optical output (**Figure Aa**). The diode's extreme sensitivity to temperature complicates the drive situation (**Figure Ab**). Consequently, the bias circuitry must dynamically adapt to temperature conditions through an automatic-power-control circuit, thus stabilizing the output at the desired level. For this reason, laser diodes have a monitoring photodetector built into their design.

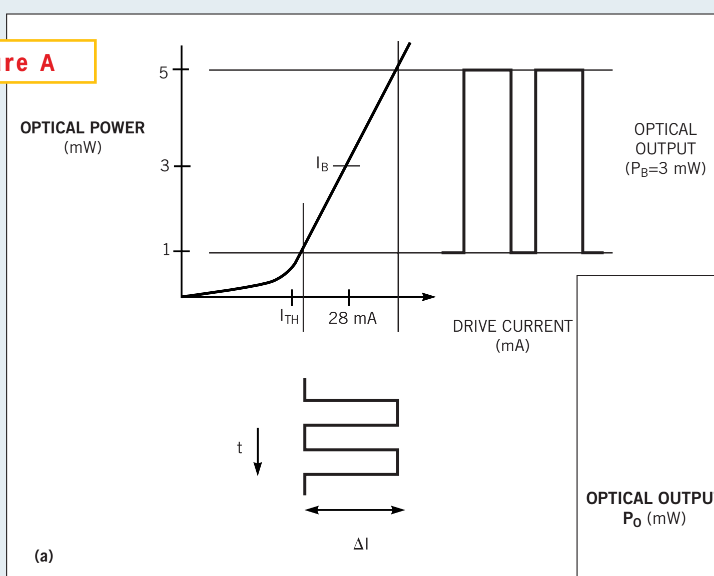
To perform the complementary photon-to-electron conversion, you most likely use a photodiode. Two types are common: the positive-intrinsic-negative (PIN) model, which provides high sensitivity, wide dynamic range (spanning as many as nine decades), stability, and fast response, and the more complex and expensive avalanche photodiode, which provides more current flow at low light levels. Depending on their construction and materials, the photodiodes have widely varying sensitivities to light wavelengths, and the photodiode window of sensitivity must match the source's wavelength. In the overall system-link budget and design, you must consider such photodiode parameters as response speed and noise.

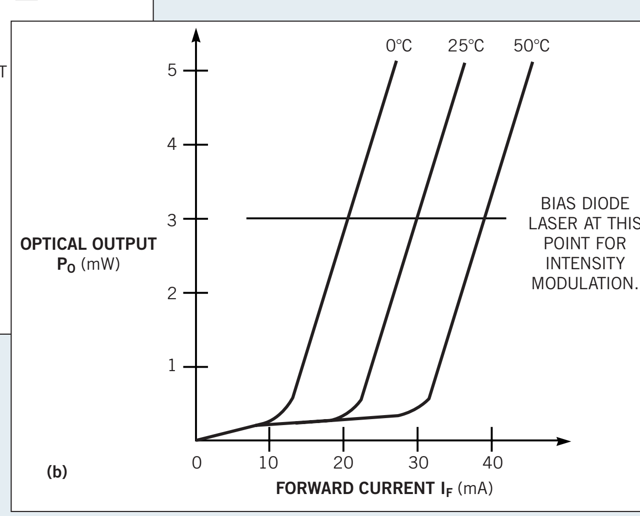
This diode noise has three primary components: dark noise, resulting from leakage current that occurs even when no light hits the diode; shot noise, a Poisson-distributed noise proportional to the intensity of light hitting the diode; and thermal (Johnson) noise, resulting from the random thermal motions of electrons in the diode material. **Reference A** provides a good discussion of transducers, associated circuits, and electro-optical systems.

REFERENCE

A. Desmarais, Louis, *Applied Electro-optics*, Prentice Hall, 1998.

Figure A





Unlike relatively linear LEDs, laser diodes do not produce an output until their drive currents exceed a threshold value (a). A laser diode's threshold and output power are very sensitive to temperature; thus, the diode requires a stabilization circuit (b) (adapted from Reference A).

large signals; jitter, a function of pulse distortion, data patterns, and noise; and reliable signal detection and decision making.

The overall receiver contains a photodetector (usually a photodiode), followed by a transimpedance amplifier, which boosts the relatively weak current flow from the transducer and converts it to a voltage. A limiting amplifier, or "1-bit quantizer," follows the transimpedance amplifier; the limiting amplifier makes the decision of whether the received-signal level corresponds to a zero or a one. The receiver must also implement a PLL to extract clock information from the received data stream. Because signal speeds and slew rates are high, circuit noise sensitivity and power-supply coupling are design concerns. Further, it's always a challenge for outputs to drive even a small inductive load at high speeds; thus, you implement much of the interface circuitry following the receiver using differential positive-emitter-coupled-logic (PECL) signals.

Some numbers give you an idea of the receiver challenge. A 622-Mbps LAN receiver can see optical signal levels as low as −28 dBm; these low signal levels are the result of loss, source-transducer inefficiency, and aging. With an extinction ratio of 10, the signal at the output of the photodetector may be as low as 3 μA p-p. Because you desire 1.6V PECL inputs to the postreceiver circuitry, you need overall gain of 1.6V/3 μA=530V/mA in the receiver, which is a lot of gain. To minimize potential system oscillation and to maximize stability, you usually need to divide the required gain between two stages, with 50 to 70 dB in the transimpedance amplifier and 45 to 65 dB in the limiter.

However, the needed high gain is a problem for larger signal levels, which can occur when the receiver is near the signal transmitter. In such cases, the photodetector output can be as high as 1 mA, and amplifier overload and recovery time—the dark side of high gain and sensitivity—become problems you need to anticipate.

All applications do not have these receiver challenges to the same degree. LANs, for example, usually cover shorter distances than telecomm applications do and thus are more susceptible to signal overload. In contrast, because of the longer distances involved, telecomm applications are more prone to noise and sensitivity issues. But even this situation is changing. As telecomm and LAN applications converge, many of their characteristics are increasingly similar. In addition, the increased use of wavelength-division multiplexing in telecomm installations means that even telecomm receivers are seeing increased optical energy and thus potential overload conditions (**Reference 1**).

The receiver's clock-recovery PLL faces the conventional tracking problem: You want wide bandwidth for fast and accurate noise tracking but narrow bandwidth to reject transmitter noise. The PLL vendor sets the PLL bandwidth and associated loop constants, based on the data rate for which the PLL is optimized. For example, a 622-Mbps link typically uses a PLL with 500-kHz bandwidth. Be sure to check the unit-to-unit consistency of the vendor's PLL parameters. These parameters can be difficult to control, and a wide range in their values causes system-to-system bit-error rate (BER) variations. Note that a typical 622-Mbps fiber-optic link strives for a BER of one error in 10^{10} bits.

Though integrating multiple functions

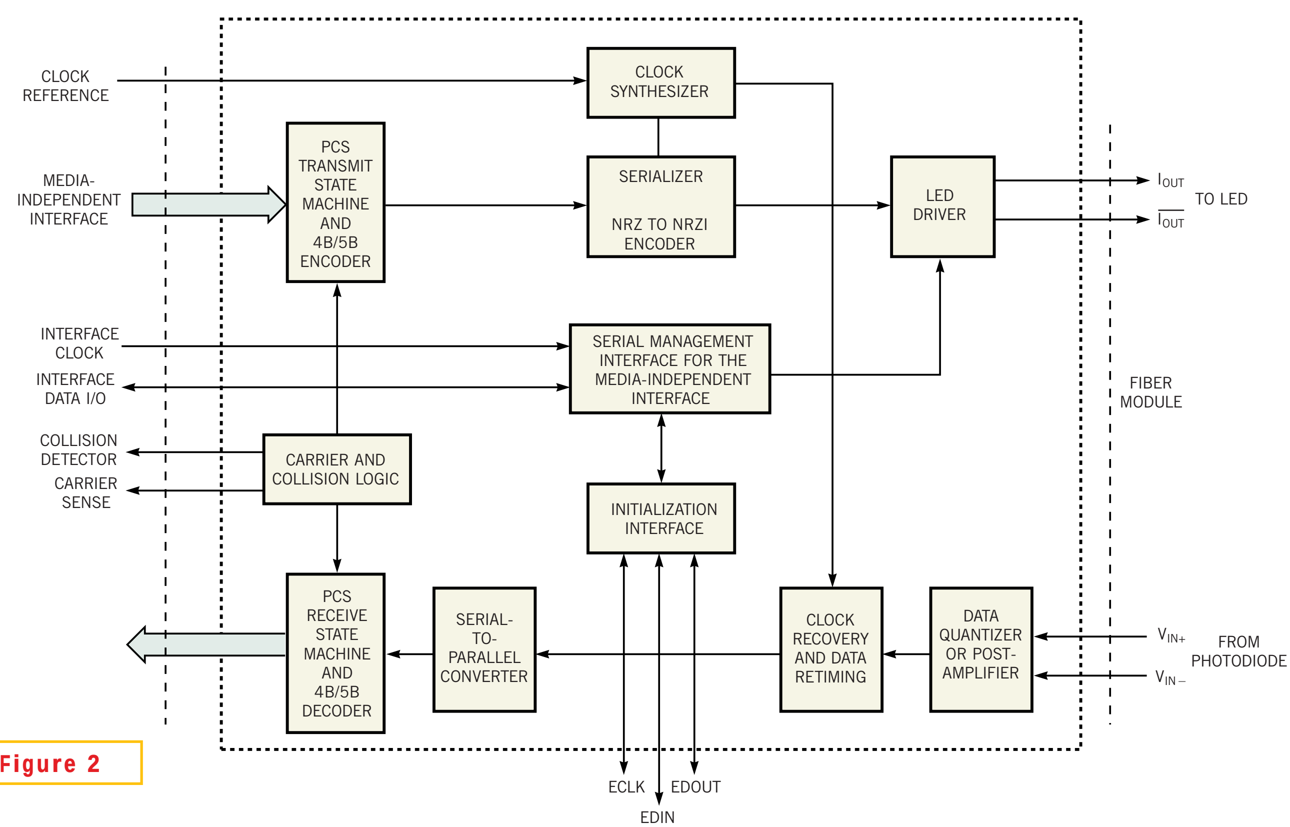


Figure 2

When working with the lower rates of 100BaseX links, you can get all the interface circuitry in one IC, such as the Micro Linear ML6696.

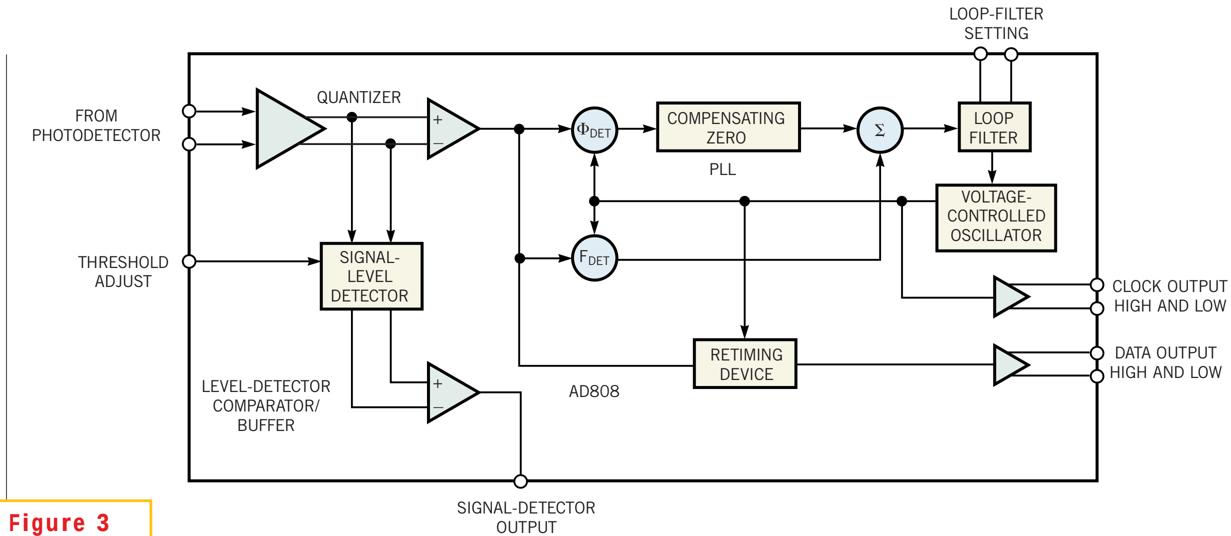


Figure 3

By using an integrated device, such as Analog Devices' AD808, after the photodiode and its preamplifier, you can build a 622-Mbps receiver channel, which prepares the data for decoding at the system level.

onto one die is the well-known general-IC trend, it's fairly difficult to integrate LED/laser-diode drivers onto the same die with the receiver circuitry or with the higher function digital-data-processing circuitry. The inherent conflict and crosstalk potential between the high-speed, high-current driver and the low-noise, wide-dynamic-range receiver interface are just too great as speeds exceed 100 Mbps. Similarly, the technical considerations and process technologies for the analog-focused driver/receiver-IC circuitry, compared with those of a high-speed, all-digital process, make these two functions an unlikely combination. For this reason, higher speed fiber-optic components rely on ICs with relatively low levels of functional integration to achieve acceptable performance.

However, you can get an IC at 100 Mbps that incorporates many fiber-optic functions in one device. Micro Linear's ML-6696, for example, integrates the entire 100BaseFX (1300-) and 100BaseSX (820-nm) physical layer, including the 60-mA LED driver and the photodetector post-amplifier, or quantizer (**Figure 2**). The dig-

VENDORS OF ANALOG FIBER-OPTIC-RELATED COMPONENTS

For more information on products such as those discussed in this article, circle the appropriate numbers on the Information Retrieval Service card or use *EDN*'s InfoAccess service at www.ednmag.com. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

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ital side of this 52-lead PLCC connects directly to the subsequent media-access controller via a media-independent interface.

Some vendors concentrate primarily on the receiver side of the link. Analog Devices offers the AD8015 wideband/differential transimpedance amplifier, an eight-pin device with 240-MHz bandwidth and 1.5-nsec rise/fall time. It suits data rates from 155.52 Mbps, where it exhibits optical sensitivity of −36 dBm, to 300 Mbps. The AD808 receiver, which has a quantizer and clock-recovery and data-retiming functions, operates to 622 Mbps with output jitter of less than 2.5 rms (**Figure 3**). The PLL-type data-recovery circuit in this IC requires no crystal. Using a single resistor, you can set a lower limit threshold for valid signal levels; below this threshold, which has 3 dB of hysteresis, you get a flag indicating that signal levels are too low for valid performance.

Other vendors offer chip sets for both the transmitting and the receiving side. Maxim, for example, offers 10 functions for 622-Mbps LANs in a three-IC set (**Figure 4**). The MAX3766 laser driver supplies as much as 60 mA of modulation current, along with a user-programmable modulation-temperature coefficient, to maintain a nearly constant extinction ratio over a wide temperature range. This driver also has APC circuitry, which uses the laser's monitor photodiode to adjust bias current and thus maintain constant output power despite temperature or age variations. Smooth-start and fault-monitoring circuitry complete the functions of the driver IC.

At the receiver, the MAX-3760 transforms photodiode currents into differential voltages and includes a dc-cancellation circuit to minimize pulse-width distortion over a 30-dB dynamic range. The device's 6.5-kΩ transimpedance gain and 560-MHz bandwidth combine to yield −31.5-dBm sensitivity, with 1-mA overload capability. The MAX3760 output feeds the MAX3761 postamplifier, a 4-mV-sensitivity device that produces a TTL/PECL output and a separate loss-of-signal-power indication. Maxim also has similar chip-set trios for 1-Gbps Fibre Channel/1.25-Gbps Gigabit Ethernet and 2.5-Gbps Fibre Channel applications.

Siemens offers its M13T029 transimpedance amplifier with gain of 30 to 100 kΩ for systems operating from 622 Mbps to 3.3 Gbps. The amplifiers' input sensitivity ranges from −23.5 to −31 dBm, depending on the bit rate; maximum input current is 2 mA. Sony supports laser diodes with its CXB1548QY driver. The driver,

A FEW VENDORS OFFER ICs THAT REACH 10-GBPS STM64/OC192 RATES.

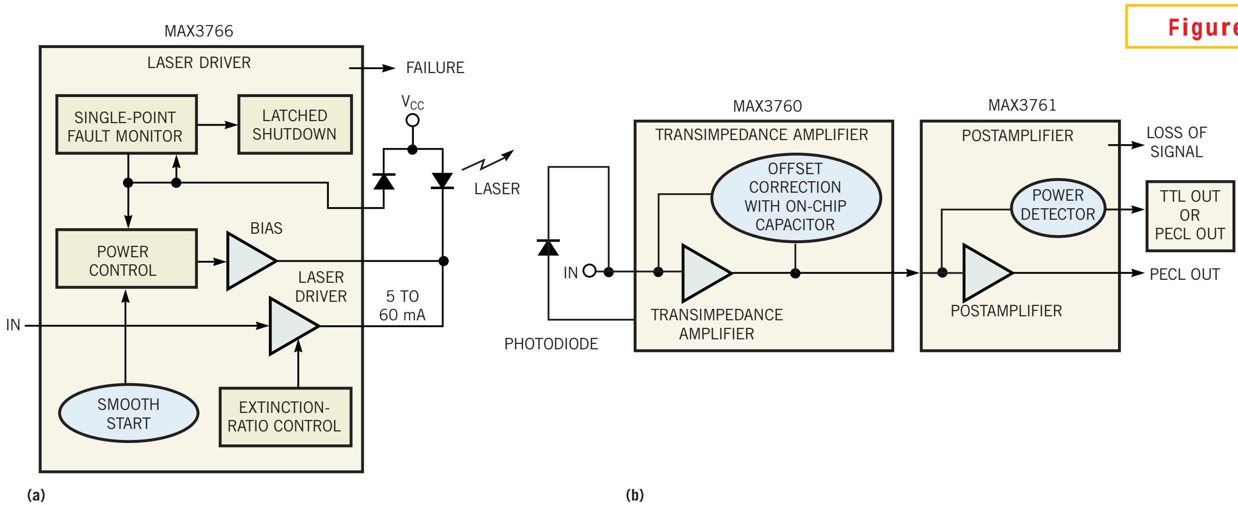
which has APC, comes in a 32-pin package. This 1.06-Gbps device consumes 360 mW from 5 and −5.2V supplies. At the receiver, the company's CXB1577Q provides 1.25-Gbps amplification, plus reshaping and regeneration, and operates from supplies as low as 3.3V.

Although Philips Semiconductors has ICs for the relatively slow 155-Mbps STM1/OC3 domain, as well as for faster devices, it is one of the few vendors with optoelectronic-interface ICs that reach 10-

Gbps STM64/OC192 rates. The CGY2110 transimpedance amplifier complements the company's CGY2111 modulator/laser driver, which has 3V p-p single-ended output and 6V p-p differential output. The CGY2110 has less than 8 pA/$\sqrt{Hz}$ input noise and consumes less than 350 mW from a 5V supply.

In the 2.4-Gbps range, Applied Micro Circuits Corp has a Model 3049 laser driver, which integrates a reference generator, modulation driver, and laser-bias block with APC and adjustable bias to maintain constant laser output power. The 32-pin, 5V IC has a built-in delay when turning on

Figure 4



Maxim's three-chip set for 622-Mbps operation provides nearly all the interface circuitry needed between the all-digital domains on the transmitting (a) and receiving (b) sides; the company offers similar chip sets for 1.25- and 2.5-Gbps operation.

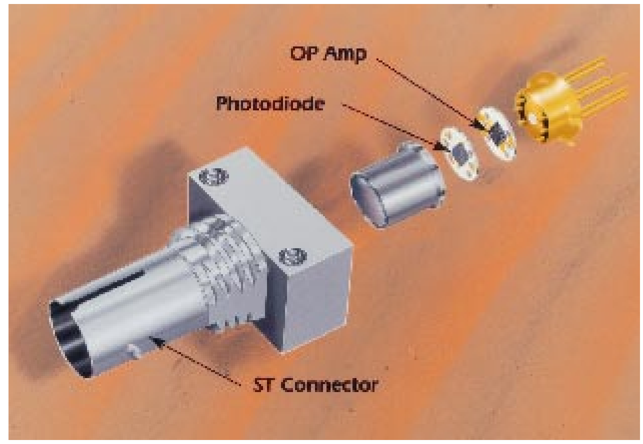
the laser-bias current to prevent momentary open-loop operation on power-up; it also includes a laser power-fail output to indicate when laser power is too low and an alarm signal for laser overdrive protection. The company also offers a companion S2036 open-fiber-control IC for Fibre Channel, which monitors the fiber link and shuts down the laser or reduces its power when it senses that the link has been disrupted. This IC meets the ANSI XT311 standard for safety, along with Food and Drug Administration and International Electrotechnical Commission (IEC) guidelines for Class 1 safety compliance.

For a broad family of laser drivers and transimpedance amplifiers, Vitesse offers devices that range from 155 Mbps to greater than 2.5 Gbps. For example, the company's VSC7924 laser driver for 2.5-Gbps devices delivers 50 mA of laser-bias current and an additional 60 mA of programmable bias current. The device operates from a 5V supply and has a rise time of less than 100 psec. For receivers, the single-ended VSC7911 and differential VSC7912 transimpedance amplifiers for 622-Mbps devices include an integrated AGC loop with a 33-μsec time constant and input-noise current density of 2.8 pA/$\sqrt{\text{Hz}}$.

Vitesse's line also includes products that eliminate your risk as you try to electronically and mechanically match photodetectors with transimpedance amplifiers—not a trivial task at gigabit rates. The company's VSC-7800 series, comprising three members, integrates both functions into one package, along with a 770- to 860-nm detector and amplifier. The fastest family member supports data rates to 1.063 Gbps.

Other vendors also integrate a photodetector and amplifier. Anadigics, for example, offers an optoelectronic IC with an 850-nm detector, for operation at 1.25 Gbps. The company's AMT128501 yields sensitivity of at least −20 dBm, with 260-psec rise and fall times and 0-dBm input overload capability.

Just because the benefits of optoelec-



An optoelectronic IC, such as Centro Vision's 100-Mbps BPX-65-100 (which is structurally similar to Anadigics' faster 1.25-Gbps AMT128501), solves some difficult electronic and mechanical problems that you may face.

tronic ICs are clearly greatest at higher data rates doesn't mean that only leading-edge users can take advantage of the concept. Centro Vision Inc has a 100-Mbps BPX65-100 receiver for 400- to 1100-nm (peaking at 900 nm) operation. The device includes a 1-mm^2 detector and amplifier in a TO-18 case, which you can get with an industry-standard ST- or SMA-type connector (**Figure 5**).

To further minimize your design challenge and risk, some vendors offer complete modules. NEC, for example, has a 156-Mbps transceiver module for distances from 50 to 100m, depending on the fiber type you use. This 650-nm, 5V module comes in an industry-standard 1×9-in. SIP. The module includes a transmitting-side LED and driver, a receiver PIN (positive-intrinsic-negative) photodiode, an amplifier, and reshaping and regeneration functions. It also has a differential PECL interface to the remainder of the system circuitry and an F07 pin-type connector for the fiber itself.

Let me know what you think. Send me your comments via fax at 1-617-558-4470 or over the internet at bill.schweber@cahners.com.

The trend toward lower supply voltages, from the common 5V to 3 or 3.6V, has not bypassed fiber-optic components. One driving factor for using a lower voltage supply is that doing so lets you use the same power supply for the fiber-related components that you use in the rest of the system. At the transmitter, the power savings from the lower supply are smaller than you may first assume, because the supply must provide relatively large amounts of current for the photoemitter, regardless of the operating voltage. The lower rail, however, with its reduced head room and design margins, makes your design more difficult. Also, because this application involves high current sourcing/sinking, your attention to quality supply decoupling and bypassing, suitable local-supply regulation, and large ground planes is even more essential.

Start your design with the vendor's evaluation/demo board and layout; virtually all vendors offer them, and most expect you to use them before they'll support your own design variation. Be sure to use detailed modeling of both basic electrical characteristics and associated parasitics, as well as of thermal factors, before you commit to production. If relevant to your application, ask the IC vendor how the parts qualified for various regulatory requirements and for conventional electrical parameters. And don't hesitate to ask about the vendor's test setup and calibration—remember that a required 0.01-unit-interval maximum jitter specification corresponds to just 4 psec of jitter at 2.5 Gbps! □

Reference

1. Schweber, Bill, "Optical amplifiers literally pump up the (photon) volume," *EDN*, July 16, 1998, pg 40.

Acknowledgments

Thanks to Thomas Freni, John Quirk, Jack Sachitano, and Brett Fox (especially for the numbers) of Maxim Integrated Products and to Tremont Miao and Larry DeVito of Analog Devices for their insight and perspectives.