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LIGHTWAVE DATA LINKS AND INTERFACES

Introduction

In the rapidly expanding market for office communications, computer interconnection, local area networks, and factory automation, fiber-optic point-to-point data links offer a cost-effective and functionally superior alternative to copper interconnection. AT&T has developed a line of miniature, low-cost, yet highly functional and reliable optical data links to address this need.

These components can be directly incorporated into systems design to provide convenient logic interfaces to the fiber-optic medium. Or, they can exist within auxiliary subsystems (lightwave interfaces) that provide, in addition to communication over optical fibers, parallel-to-serial translation and standard communications interfaces.

Data Links

Fiber-optic data links are intended for applications in which distances are relatively short, and where cost, size, and reliability are paramount. Such requirements are characteristic of the local area network or campus computing facility where moderate amounts of information are transmitted among several locations. This is in contrast to the long-haul transmission market, which involves extremely high capacity and long distances. As a result of the different requirements, data links generally use low-cost light-emitting diode (LED) sources, multimode fiber, and simple junction photodetectors. Long-haul applications use

semiconductor lasers, single-mode fiber, and more complex receivers.

Brackett et al.¹ reported one of the earliest applications of optical fibers by AT&T in the 5ESS™ digital switching machine. In this case, links operating at 32 megabits per second (Mb/s) carried 256 digitized telephone conversations and associated network and timing applications between different parts of the switch. These 32 Mb/s links are still operational. Other applications of low-cost fiber-optic subsystems in short-haul markets are relatively few and recent.

The ODL® 50 and ODL® 200 data links (Figure 1) cover applications from 1 to 200 Mb/s and provide a smaller package and more convenient interface than the earlier design.^{2,3} The links transmit optical data over two kilometers (km) or more, including allowances for several interconnections in the optical path. The links themselves consist of transmitter and receiver modules in 16-pin dual in-line packages. Companion clock-recovery circuits in separate packages are available for each of the designs.

With the new AT&T ST® fiber connector,⁴ the data link can have the low package height consistent with the 0.5-in board spacing common to many electronic system designs. This also gives the convenience of a connectorized package instead of the fiber pigtail more common in transmission system designs.

Optical Sources and Detectors. The light-emitting diode (LED) source for the ODL 50 transmitter is the same GaAlAs (gallium aluminum arsenide) high-radiance, double-heterojunction LED used in the original 32 Mb/s design.⁵ Now, however, the optics interface has been improved for use with 62.5- μ m core multimode optical fiber, rather than the earlier

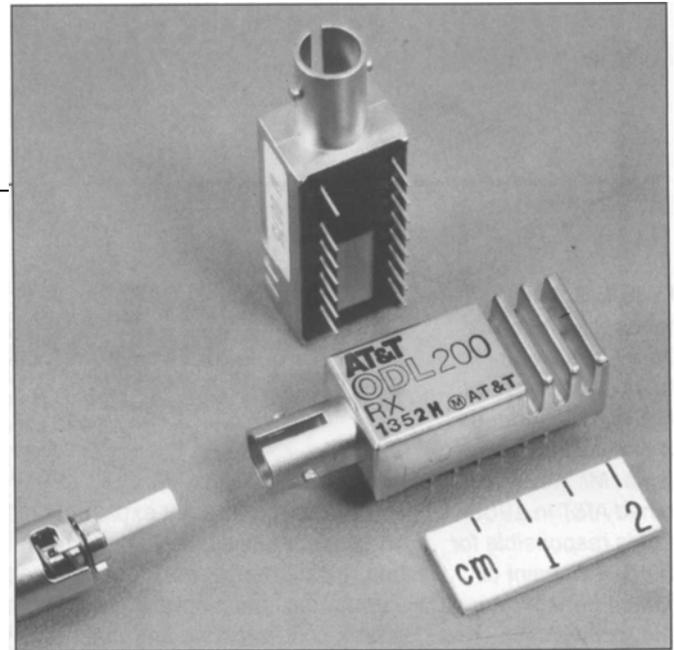
Figure 1. The ODL[®] 200 optical data link.

50- μm fiber design. The larger core size permits almost twice as much optical power to be launched into the fiber. Even larger core sizes could be considered. But pulse degradation (due both to cabling effects and to modal dispersion) eventually offsets the advantage of the larger launched power for all but the shortest spans.

For a transmission distance of approximately two km, both optical attenuation and pulse dispersion must be taken into account in determining the maximum loss between the transmitter and receiver. With the 0.87- μm wavelength radiation emitted by the GaAlAs diode, up to 50 Mb/s, the expected dispersion penalty of about 2 dB is acceptable. Above this rate, however, the penalty rises rapidly, reducing the available transmission distance.

For the ODL 200 transmitter, then, we use the longer 1.3- μm wavelength of indium gallium arsenide phosphide (InGaAsP) diodes in which fiber dispersion is minimized and loss is much lower. The fiber SLC[®] system has used such a diode for some time, but the doping of the active layer has been improved (at the expense of output power) to achieve the higher speed required at 200 Mb/s.⁶ An integral lens, made with photolithographic techniques and incorporated into the diode itself, reduces the angular divergence of light emitted from the surface of the diode, thereby simplifying the optical interface to the fiber.⁷

For both the ODL 50 and the ODL 200 transmitters, the LED is mounted on a small

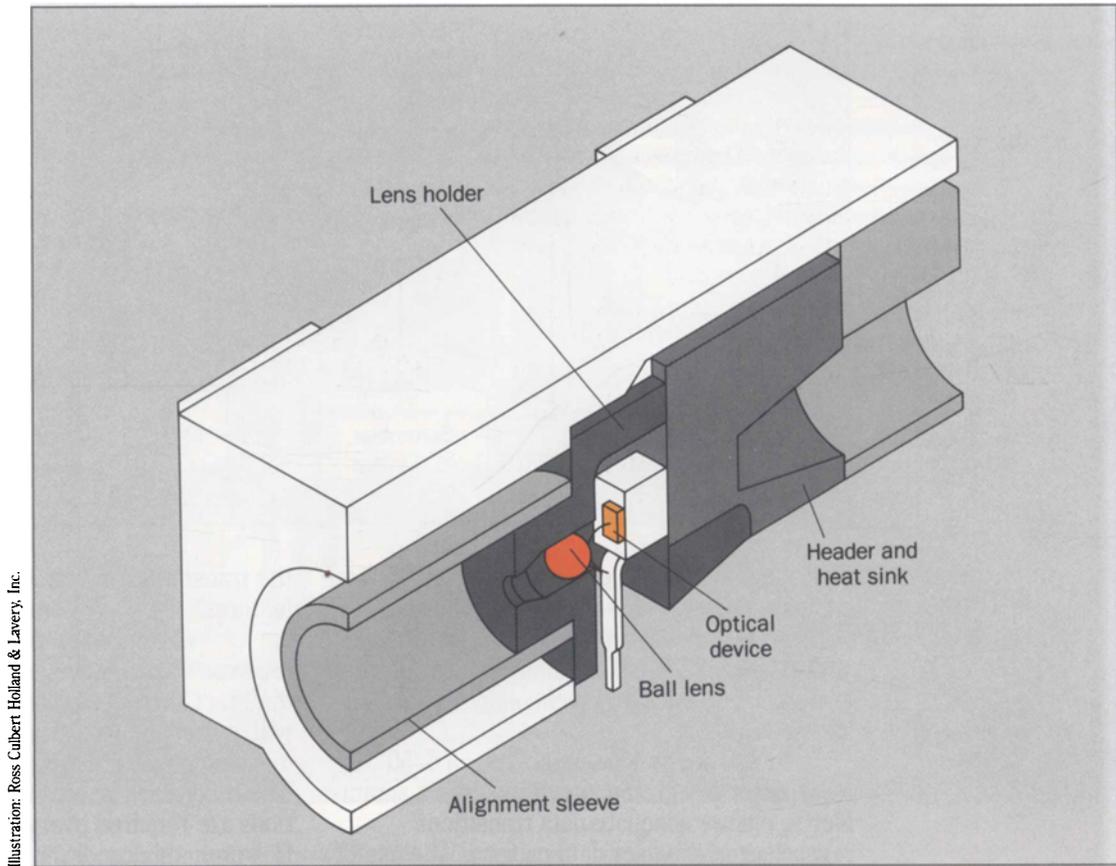


die-cast header and heat sink for handling and testing. The header is then inserted in an optical subassembly (see Figure 2) that provides alignment to the optical connector plug. A spherical lens in the optical subassembly improves optical coupling and protects the diode surface from direct contamination from outside the module.

For the ODL 50 data link, the use of a short-wavelength emitter permits the use of a silicon diode detector, an inexpensive, reliable, and effective light monitor. A special low-voltage design eliminates the need for an extra-bias voltage supply. This material is not sensitive at the 1.3- μm wavelength of the InGaAsP LED, however, so an InGaAs photodetector is required.

We have chosen a planar, back-illuminated PIN device (positive-intrinsic-negative) that was originally designed for submarine cable application.⁸ This diode has a very low capacitance, low and stable dark current, and can be passivated easily because of the planar structure, thus improving reliability. While avalanche photodiodes are available at both wavelengths, they require a high-voltage bias and are substantially more expensive and

Figure 2. Optical subassembly outline.



complicated to use than the simple PIN devices, and are also less reliable. Because our objective is reliability at low cost, the PIN devices are a better choice for most applications.

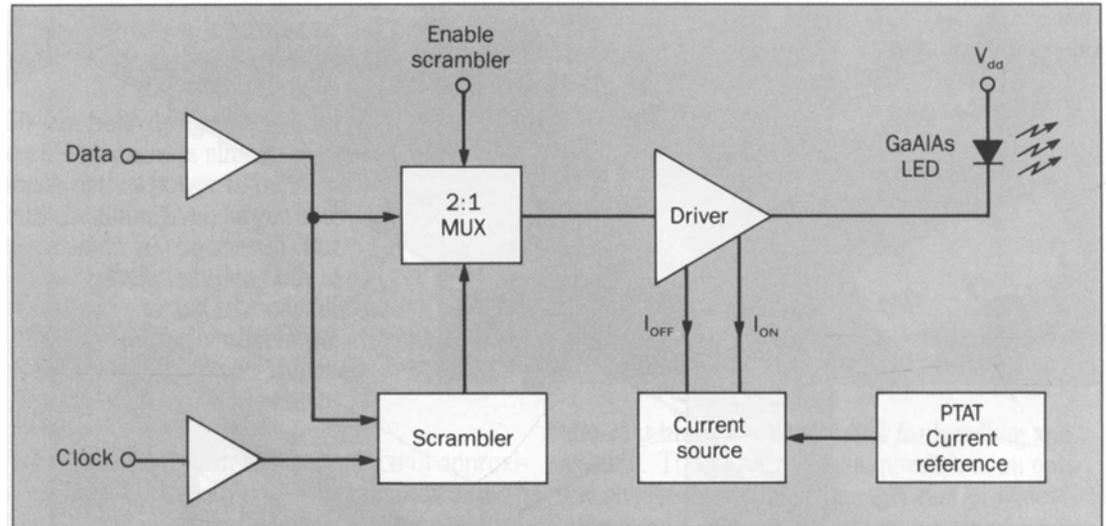
Optical coupling of the silicon PIN is straightforward, because the geometry is almost identical to the transmitters. Figure 2 illustrates the optical subassembly, which is nearly the same for all the modules except the ODL 200 receiver. The long-wavelength PIN

required some modification because of the back illumination. The diode is illuminated through a hole in a ceramic substrate, which becomes the device header. Optical coupling is provided through a short fiber stub.

Circuit Design

A key product design objective was to put all required functions on a single integrated circuit for each module, making a simpler, smaller package design and minimizing assem-

**Figure 3. ODL® trans-
mitter block diagram.**



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bly costs. This has been achieved with 1.5- μm complementary metal-oxide semiconductor (CMOS) technology for the ODL 50 codes and with microwave complementary bipolar integrated circuit (MCBIC) technology for the ODL 200 codes.

The ODL 50 Transmitter. The ODL 50 transmitter integrated circuit includes a scrambler to ensure adequate data transitions regardless of the user data pattern. The use of the scrambler is optional, but when in use, there are few restrictions on the bit patterns that may be transmitted over this link. The complementary descrambler could not be included in the receiver integrated circuit because of the already high complexity of that function. Instead, the descrambler is included as part of the separate clock recovery module. Additionally, a proportional-to-absolute-temperature (PTAT) current reference compensates for the change in output power from the LED with temperature. A block diagram of

the transmitter in Figure 3 shows these features.

The ODL 50 Receiver. The ODL 50 receiver¹⁰ has a high-sensitivity front end able to detect currents as low as 100 nanoamperes, with automatic gain control (AGC) to provide a dynamic range greater than 50 dB (electrical). The receiver is ac coupled, so that data transitions are required every seven pulses. However, this condition is ensured by using the scrambler as described.

Two postamplifier stages boost the signal level to that required by the final comparator, which provides logic level outputs through an output buffer stage. The overall signal gain on this chip is over 100 dB at 25 MHz. Careful layout and package design is essential to minimize coupling from output back to the very sensitive PIN input node. The only components external to the receiver IC in the module are for power supply bypassing.

The ODL 200 Receiver. Figure 4 is a

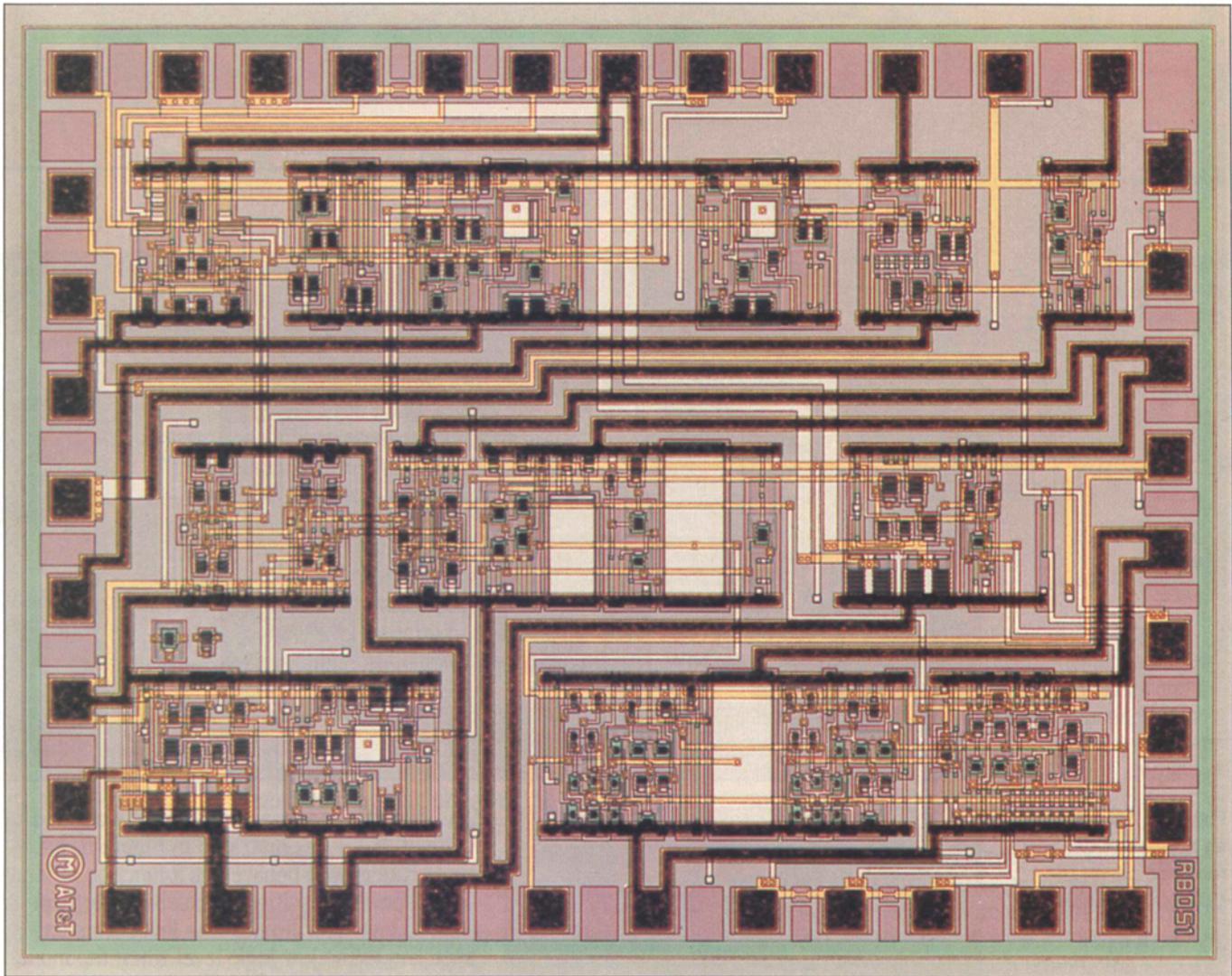


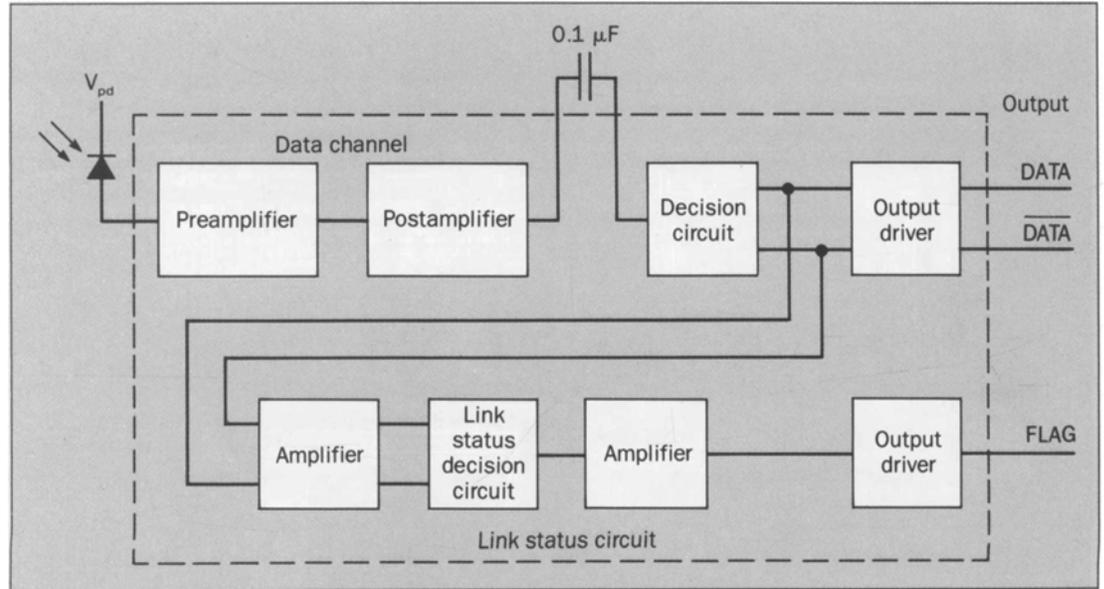
Figure 4. Microphotograph of the ODL[®] 200 receiver integrated circuit.

microphotograph of the ODL 200 receiver integrated circuit. A block diagram is shown in Figure 5. This receiver¹² again provides the preamplifier, postamplifier, and comparator functions similar to the ODL 50 design. However, because of the higher speed and interfacing requirements, the chip has been realized in MCBIC technology with two levels of metallization. Again, the IC works with a single 5-volt power supply, and versions exist for either positive or negative supply voltages. The output levels are standard emitter-coupled logic (ECL) signals referenced to the power

supply voltage.

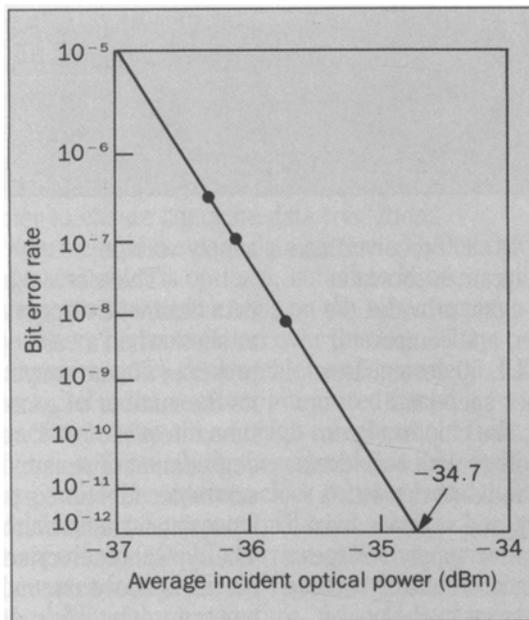
There is a signal path parallel to the data channel that provides a status flag output to show when a valid optical input signal is present. The ac coupling of the signal path limits the number of consecutive 1s or 0s to a time interval of < 1 microsecond to avoid degradation of sensitivity. No scrambler/de-scrambler function is provided. Thus, the user input data stream must satisfy this restriction. The typical receiver sensitivity is -35 dBm (decibels above one milliwatt) average optical power for a bit error rate of 10^{-9} at 200 Mb/s.

Figure 5. Block diagram of the ODL® 200 receiver.



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Figure 6. Bit error rate as a function of received power for ODL 200® receiver.



The dynamic range is about 23 dB, achieved without AGC. As illustrated in Figure 6, bit error rate is well-behaved as a function of input optical power, resulting in excellent performance to low error levels. The link status flag switches to the low logic level when the input power drops below -36 dBm.

The ODL 200 Transmitter. The transmitter, again an MCBIC design, provides a current drive of 125 milliamperes to the LED. Here, there is no scrambler; the circuit consists simply of an input stage, buffer, and output driver. Output power averages -17 dBm with an extinction ratio of at least 20. Switching times are typically 1.3 nanoseconds.

Except for the ODL 200 transmitter, the integrated circuits are directly wire-bonded to a multilevel printed wiring board. Output leads for the module are directly inserted into the substrate. Power-supply-bypassing chip

Figure 7. The ODL® RS232-1 lightwave interface.

capacitors are surface-mount soldered to the board. Thus, the substrate assembly provides a complete, testable electrical subassembly. Because of the large power consumption of the ODL 200 transmitter driver, the integrated circuit is die-bonded to a multilayer ceramic substrate that contains an integral heat spreader. Otherwise, the configuration is similar to the other circuits.

Final assembly of the modules consists of attaching the completed electrical and optical subassemblies together in a plated, die-cast outer housing that provides the physical attachment for the ST connector and electrical shielding for the entire module.

Interfaces

The transmitter-receiver pairs described above provide a direct and convenient board-level interface between electronic logic and optical transmission. Because little signal processing is included within the modules, there is also design flexibility. The complexity of the final system can range from the simplest terminal interface to complex high-speed computer-to-computer communication. The ODL RS232-1 full-function standard interface is an example of a simple system design with the ODL modules (Figure 7).

The ODL RS232-1 is a stand-alone subsystem that translates the standard parallel RS232 data and control signals into a serial for-



mat suitable for transmission over an optical fiber. The multiplexing capabilities of the interface circuit provide for four control lines and a clock line in addition to the data channel. It is possible to combine several data channels up to 19.2 kilobits per second (kb/s) into a simple multiplexer if all the control lines are not required. Such operation may be particularly attractive for clustered communications interfaces such as engineering workstations or in factory automation terminals. The heart of the interface is the ODL 50 receiver and a modified ODL 50 transmitter, which provide the actual optical interfaces. Because of the small size of these modules, the ODL RS232-1 itself is compact enough to be attached directly to the serial output of a computer or terminal and provide a direct link of up to one km. Data transmission speeds up to 64 kb/s (synchronous) or 100 kb/s (asynchronous) are permitted over the main data channel.

Summary

This interface is one illustration of the general capability provided by the ODL product family. Obviously, much more sophisticated high-speed interfaces are possible using the full

data rates of the ODL 200 and ODL 50 designs. Many new applications are currently in the development stage. As these ideas are realized, we may expect to see far broader application of fiber optics than the now common use in long-distance telephone communications. Increased production of these modules and their general availability will reduce prices and encourage still more applications.

Acknowledgments

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