UCRL-JC-129066
PREPRINT

Cascaded Wavelength Division Multiplexing for Byte-Wide Optical Interconnects

R.J. Deri
S. Gemelos
H.E. Garrett
R.E. Haigh
B.D. Henderer
J.D. Walker
M.E. Lowry

This paper was prepared for submittal to the
9th Annual Workshop on Interconnections Within High Speed Digital Systems
Santa Fe, NM
May 17-20, 1998

November 17, 1997

Lawrence Livermore National Laboratory

Cascaded Wavelength Division Multiplexing for Byte-wide Optical Interconnects

R. J. Deri, S. Gemelos, H. E. Garrett, R. E. Haigh,
B. D. Henderer, J. D. Walker, and M. E. Lowry

Lawrence Livermore National Laboratory
7000 East Avenue, mailstop L-145
Livermore, CA 94550
deri1@llnl.gov

Abstract

We demonstrate a wavelength division multiplexing approach for byte-wide optical interconnects over multimode fiber optic ribbon cable using filters based on common plastic ferrules. A dual wavelength link with eight cascaded filter stages exhibits bit error rates $\leq \bullet 10^{-14}$.

Cascaded Wavelength Division Multiplexing for Byte-wide Optical Interconnects

R.J. Deri, S. Gemelos, H.E. Garrett, R.E. Haigh, B.D. Henderer, J.D. Walker, and M.E. Lowry
Lawrence Livermore National Laboratory, Livermore, CA 94550

Optical interconnects based on parallel transmission over multimode fiber (MMF) ribbon cable are emerging as a robust, high-performance data link technology [1,2,3]. While this technology has primarily been implemented as single wavelength, point-to-point links, it can be significantly enhanced by wavelength division multiplexing (WDM). WDM enables both increased point-to-point bandwidth as well as more complex interconnect topologies and routing approaches, which are particularly attractive for high performance computing platforms[4]. Research in this area suggests that transceivers for point-to-point links can be realized.[5,6] Exploiting the potential richness of WDM networks, however, also requires a low-loss routing fabric which includes small footprint add/drop multiplexers. Low insertion loss is critical for this technology because the transceivers exhibit link power budgets well below that of telecom WDM systems and because the multimode fiber cabling precludes the use of optical amplifiers. While high-performance filters can be realized for single-fiber applications[7], achieving high-performance, small footprint devices with ribbon cable is significantly complicated by MMF's high NA=0.275 and large core (62.5μm). Here we demonstrate such a filter technology, which can enable WDM networking using byte-wide transceivers, and demonstrate a dual wavelength link through a cascade of eight WDM filters.

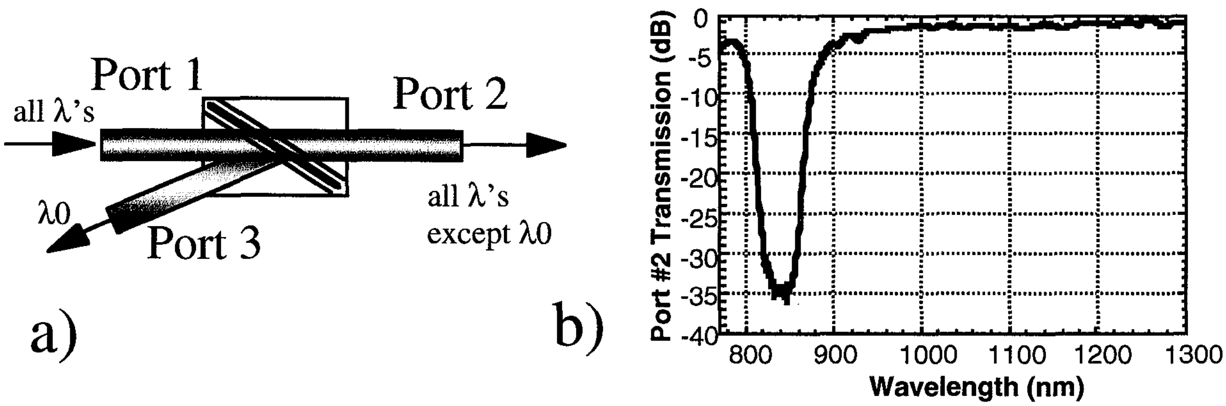

Fig. 1 Filter schematic (a) and typical port 2 response (b).

Our filters are 3-port devices suitable for add/drop multiplexing, which employ thin film interference filters sandwiched between multimode fibers as shown in figure 1. In contrast to previous reports of related devices,[8] we employ high index materials for the filter coating to minimize bandpass spreading and polarization sensitivity while maintaining a substantial angle of incidence (30 degrees) to ease optomechanical packaging, and use common, commercially available connector ferrules to maintain fiber alignment. These ferrules use injection molded plastic to provide low cost, precision optical positioning of 12 parallel fibers via passive (guide-pin) alignment, [9] and are frequently used for transceiver and cable connectorization. Guide pin alignment enables 95% passive assembly of our filter, and can therefore provide low cost filters with available ferrule technology. Since the ports are ferrules, additional connectorization is avoided. Our small filter footprint (7.8x6.4x5.7 mm^3) is limited by ferrule size. We fabricated nine filters using a conventional 1/4-wave Bragg stack coating. They exhibit a low insertion loss (1.0 dB avg., 1.5 dB max.), port 2 crosstalk suppression better than 30 dB, and a 40 nm bandwidth (fig. 1b)--which was specifically designed for compatibility with available commercial transceivers. Simulation shows that our filter approach is suitable for channel separations as small as 15-30 nm, and 5-10nm with some modification.

We demonstrated a dual wavelength link based on our WDM filters and commercially available, byte-wide transceivers (Optobahn, Optobus). 2^{23}-1 PRBS signals at ≈850 and 1310nm, at bit rates of 500 and 1000 Mbit/s/fiber respectively, are routed through a cascade of up to eight filters and ≈40m of 62.5μm core, GRIN fiber ribbon as shown in fig. 2. This link exhibited 9dB insertion loss at 1300 nm and yielded a bit error rate below $1 \cdot 10^{-14}$, including crosstalk effects between different wavelengths and different fibers in the ribbon cables. Shaking of the fiber to induce potential error rate floors had no effect, indicating that the filters introduce negligible mode selective loss.

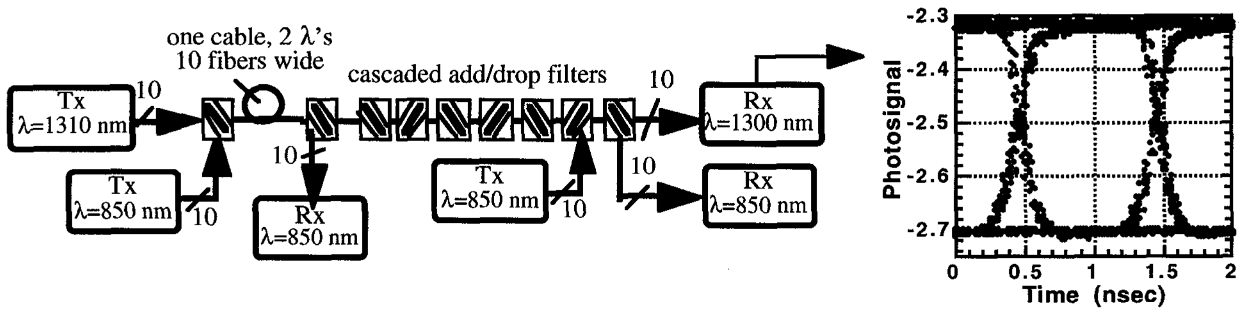

Fig. 2: Filter cascade demonstration schematic and eye diagram for transmission through 8 filters at 1 Gb/s. Cascaded filters were each separated by ≈4 m fiber cable.

In conclusion, our results demonstrate that two channel, byte-wide WDM can be achieved using new, high-performance filters and existing byte-wide transceivers. The filters are constructed from widely available ferrules to minimize alignment and connectorization costs. This technology directly enables several interesting WDM interconnects, such as chordal rings. More significantly, our demonstration of error-free transmission over large cascades opens the door to WDM source-routing of byte-wide interconnects, in which single-hop source routing to a large number of destinations will be limited by the wavelength channel count rather than the optical loss budget. For example, our 8-fold filter cascade enables single-hop source-routing to as many as 2^8=256 independent destinations. Since our filter approach is extensible to 5-15 nm channel density, the combination of this technology with recent advances in byte-wide WDM sources (eg: [6]) will enable byte-wide WDM fabrics with appreciable source routing capability and high channel bandwidth.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48, and was partially supported by ARDC funding.

References

[1] Y.-M. Wong et al., *J. Lightwave Technol.* LT-13, 995 (1995).
[2] M. Lebby et al., *Proc. 1996 Electron. Components & Technol. Conf.*, p. 279 (1996).
[3] K. S. Giboney, *Proc. SPIE Optoelectron. and Packaging IV* (February 1997).
[4] R.J. Deri et al., *Proc. 3d Massively Parallel Proc. using Opt. Interconn.*, p. 62 (1996).
[5] S.Y. Hu et al., in *Proc. 1997 IEEE LEOS Annual Mtng.*, paper TuJ4 (1997).
[6] C. Chang-Hasnain, in *Proc. 1997 IEEE LEOS Annual Mtng.*, paper WJ1 (1997).
[7] L. Aronson et al., presented at *OFC '97* (postdeadline paper).
[8] H. Yanagawa et al., *J. Lightwave Technol.* LT-7, p. 1646 (1989).
[9] T. Satake et al., *Proc. 1994 Electron. Components & Technol. Conf.*, p. 994 (1994).