Penalty-free transmission at 10 Gbit/s through 40 cascaded 1-nm arrayed waveguide multiplexers

Nissov, Morten; Jørgensen, Bo Foged; Pedersen, Rune Johan Skullerud

Published in:
Optical Fiber Communication. OFC 97., Conference on

Link to article, DOI:
10.1109/OFC.1997.719680

Publication date:
1997

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Nissov, M., Jørgensen, B. F., & Pedersen, R. J. S. (1997). Penalty-free transmission at 10 Gbit/s through 40 cascaded 1-nm arrayed waveguide multiplexers. In *Optical Fiber Communication. OFC 97., Conference on* (pp. 49-50). IEEE. https://doi.org/10.1109/OFC.1997.719680

---

1. S. Sasaki, K. Sekine, N. Kikuchi, in *Optical Fiber Communication Conference*, Vol. 4, 1994 OSA Technical Digest Series (Optical Society of America, Washington, D.C., 1994), paper TuD2.
2. F. Forghieri, R.W. Tkach, A.R. Chraplyvy, D. Marcuse, in *Optical Fiber Communication Conference and International Conference on Integrated Optics and Optical Fiber Communication*, Vol. 4, 1993 OSA Technical Digest Series (Optical Society of America, Washington, D.C., 1993), paper FC4.
3. M. Suyama, H. Iwata, S. Harasawa, T. Naito, in *Optical Fiber Communication Conference*, Vol. 2, 1996 OSA Technical Digest Series (Optical Society of America, Washington, D.C., 1996), paper PD26.
4. K. Sekine, N. Kikuchi, S. Sasaki, H. Ikeda, presented at Optoelectronics and Communications Conference (OECC) '96, paper 17B2-4.

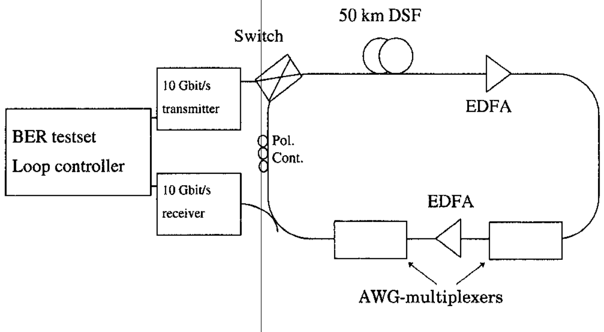
TuJ6 **3:30pm**

Penalty-free transmission at 10 Gbit/s through 40 cascaded 1-nm arrayed waveguide multiplexers

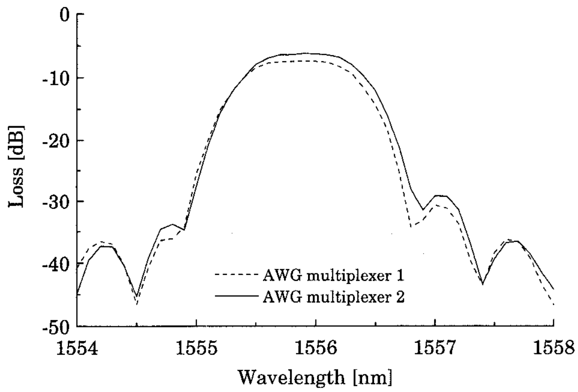
Morten Nissov, Bo Foged Jørgensen, Rune J.S. Pedersen,
Center for Broadband Telecommunications, Department of Electromagnetic Systems, Technical University of Denmark, Bldg. 348, DK-2800 Lyngby, Denmark; E-mail: mn@emi.dtu.dk

Cascaded optical add-drop multiplexers (OADM) and optical cross connects (OXC) are key components in optical wavelength-division multiplex networks. OADMs with filtering of the passing signals and OXCs can be constructed by the use of wavelength-division multiplexers. Cascadability of multiplexers is therefore vital for the network performance. The actual transfer function of multiplexers is important,[1] because the available end-to-end bandwidth between connected nodes in optical networks with cascades of OXCs and OADMs is given by the product of the transfer functions. In this paper, we demonstrate the cascadability of arrayed waveguide (AWG) multiplexers[2] in a recirculating loop experiment at 10 Gbit/s and show that up to 40 multiplexers each with a 3-dB bandwidth of ~1 nm and sharp roll-off characteristics can be passed penalty free.

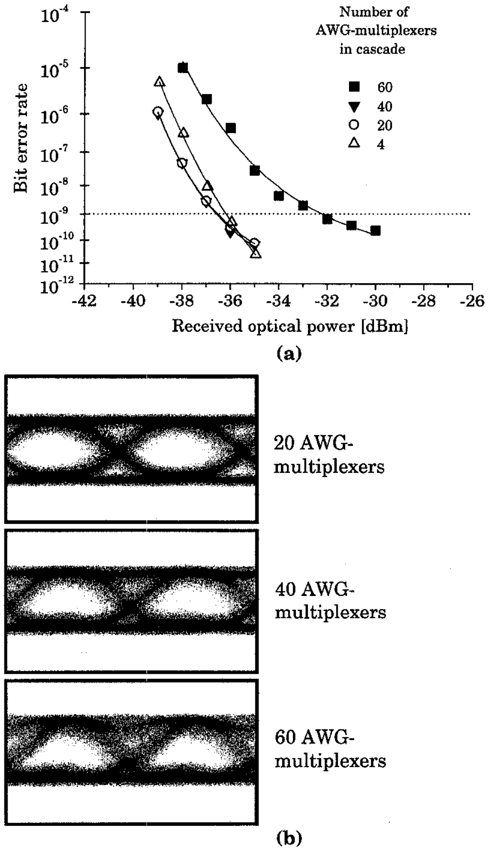
Figure 1 shows the experimental set up. A 1.556-μm distributed-feedback laser is used as signal source and the output light is modulated at 10 Gbit/s by an external modulator using a pseudorandom binary sequence with a word length of 2^{31}-1. The loop consists of 50 km of dispersion-shifted fiber (DSF) followed by two AWG multiplexers. The transfer functions are shown in Fig. 2. The insertion loss of the two multiplexers are 6.2 dB and 7.4 dB, respectively, and each has a 3-dB bandwidth of 0.95 nm. The power into the transmission fiber is +1.5 dBm. The two erbium-doped fiber amplifiers (EDFAs) compensates losses of the transmission fiber and the multiplexers. The signal is recirculated in the loop until the desired number of multiplexers have been passed and then bit error rates (BER) are measured using an optically pre-amplified receiver with an optical 3-dB bandwidth of 40 GHz.



TuJ6 Fig. 1. Schematic diagram of recirculating loop setup for measuring cascading properties of AWG multiplexers.



TuJ6 Fig. 2. Measured power transfer function for the two AWG multiplexers (AT&T × 1450 D).



TuJ6 Fig. 3. Experimental results: (a) BER vs received power after transmission through: 60, 40, 20, and 4 AWG multiplexers and (b) eye diagrams after transmission, 20 ps/div.

BER curves measured for a cascade of 4, 20, 40, and 60 multiplexers are shown in Fig. 3(a). No significant penalty is seen for cascades of up to 40 multiplexers whereas a cascade of 60 multiplexers results in a penalty of $\sim$4 dB. Eye diagrams for 20, 40, and 60 multiplexers are shown in Fig. 3(b). For 20 multiplexers (corresponding to 10 loop round trips) the eye is symmetrical with no pulse distortion and the operation is penalty free. For 40 multiplexers pulse distortion with a flattening of the bottom of the eye can be seen, but the operation is still penalty free. After 60 multiplexers the pulse distortion is more severe and causes a large penalty.

Calculations based on the power transfer functions of the multiplexers shows that cascading of 60 multiplexers results in a 3-dB bandwidth of $\sim$27 GHz. We believe that this narrow bandwidth in combination with fluctuations in laser wavelength and multiplexer center frequency causes the pulse distortion.[3]

In conclusion, we have shown experimentally that at least 40 arrayed waveguide multiplexers with a 3-dB bandwidth of $\sim$1 nm can be cascaded penalty free at 10 Gbit/s provided that the wavelength of the signal laser is well aligned in the passband of the multiplexers.

Lycom A/S is acknowledged for supplying transmission fiber and erbium-doped fiber. The work is partly supported by CEC within the ACTS METON project and the Danish Technical Research Council.

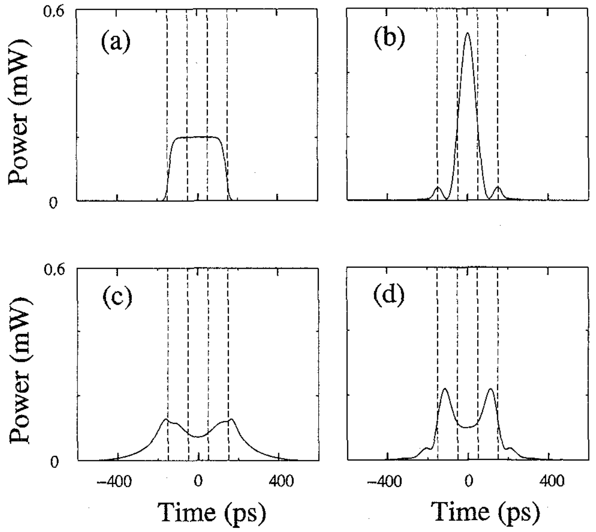
1. M.J. O'Mahony, presented at 21st European Conference on Optical Communication ECOC'95, Brussels, Belgium, September 17–21, 1995, paper Tu.B.T.3.
2. C. Dragone, IEEE Photon. Technol. Lett. **3**, 812–815 (1991).
3. N.N. Khrais, F. Shehadeh, J.-C. Chiao, R.S. Vodhanel, R.E. Wagner, in *Optical Fiber Communication Conference*, Vol. 2, 1996 OSA Technical Digest Series (Optical Society of America, Washington, D.C., 1996), paper PD33.

TuJ7 3:45pm

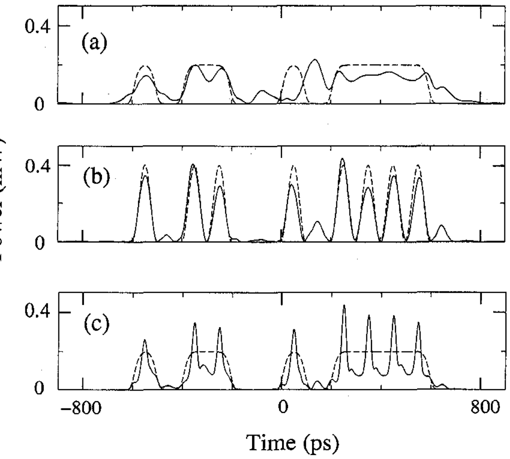
Improvement of NRZ signal transmission through phase modulation

L. Ding, E.A. Golovchenko, A.N. Pilipetskii, C.R. Menyuk, P.K.A. Wai,* *Department of Computer Sciences and Electrical Engineering, Univ. of Maryland–Baltimore County, Baltimore, Maryland 21250; E-mail: lding2@gl.umbc.edu*

Dispersion maps are required for successful nonreturn to zero (NRZ) transmission, as they allow signals to avoid the deleterious effects of four-wave mixing while still experiencing an average dispersion that is nearly zero. These maps work quite well when the power in a single channel is low, <0.05 mW (path averaged), and the dispersion map is short, less than a few hundred kilometers. However, when the power increases or the length of the map increases, pulses with a fixed phase tend to compress or expand, distorting the output signal. One wishes to use the largest signal power possible before distortion occurs to avoid the deleterious effects of spontaneous emission noise from the Er-doped amplifiers. Moreover, in wavelength-division multiplexed (WDM) systems, only one channel can be perfectly compensated in a short dispersion map; the others are compensated at the end of the transmission and thus experience a long effective dispersion map. Therefore, finding ways to minimize the distortion is of critical importance. Here, we will show that phase modulation greatly diminishes the signal distortion at high powers and with long maps, which in turn can be used by the system designers to improve the system performance by operating with higher powers. This approach was suggested by the recent results of Bergano *et al.*[1,2] showing that bit-synchronized phase modulation improves system performance.



TuJ7 Fig. 1. Temporal shape of three consecutive 1 bits surrounded by 0s for (a) the initial pulse, (b) at 10,000 km with dispersion compensation at the end the transmission, (c) at 10,000 km with initial compensation, and (d) at 10,000 km with split compensation. All signals at the end of transmission were filtered by a 40-GHz Bessel filter. The dashed lines show the time slots.



TuJ7 Fig. 2. A 16-bit (0010110010111100) pulse train at 10,000 km after filtering by a 40-GHz Bessel filter. The dashed curve is the initial pulse train, (a) without modulation, (b) with bit-synchronous amplitude modulation and phase flip, and (c) with bit-synchronous sinusoidal phase modulation.

We studied computationally a single-channel 10-Gbit/sec NRZ pulse stream with a path-averaged power of 0.1 mW. We used a span of normal dispersion fiber at $D_1 = -2$ ps/nm-km as the transmission span and a span of anomalous dispersion fiber at 17 ps/nm-km as the compensation span, with a total dispersion of zero. At the end of the transmission, a 20th order Bessel filter is used.

We considered three different compensation schemes for the dispersion. In the first, the compensation span is after the transmission span; in the second, it is before the transmission span; and in the third, it is split. Figure 1 shows our simulation results for a sequence of three 1 bits