Simultaneous OTDM Demultiplexing and Detection Using an Electroabsorption Modulator

Volkan Kaman, *Student Member, IEEE*, Adrian J. Keating, *Member, IEEE*, Sheng Z. Zhang, *Member, IEEE*, and John E. Bowers, *Fellow, IEEE*

***Abstract*—A traveling-wave electroabsorption modulator is used to simultaneously demultiplex and electrically detect a single 10-Gb/s channel from a 20-Gb/s optical time-division multiplexed data stream while transmitting the other channel in an optically transparent manner. A bit-error-rate penalty of 0.5 dB and an error floor were observed for the dropped channel due to residual absorption of the other channel. Error-free operation was achieved for the transparent channel.**

***Index Terms*—Demultiplexing, electroabsorption, optical fiber communication, optical switches, photodetectors, traveling wave devices.**

I. Introduction

ELECTROABSORPTION (EA) modulators are suited to optical time-division-multiplexing (OTDM) network applications as their nonlinear transfer function permits narrow optical switching windows with large extinction ratios. Recently, there have been several demonstrations of key processing features required in OTDM systems, such as optical short pulse generation [1], optical demultiplexing [2], [3], optical regeneration [4], [5] and drop and insert multiplexing [6] using EA modulators. The ability to drop a single channel from a high-speed OTDM data stream is significant at a network node since optical demultiplexing is performed while still transmitting the other channels in an optically transparent manner for further processing. This has the advantage of optical power conservation in contrast to standard optical demultiplexing (for example, using an EA modulator) in which the other channels are suppressed [2]. It is also desirable to perform the demultiplexing (or channel drop) and optical-to-electrical (O/E) conversion simultaneously using a single device in order to reduce the cost and complexity of the node. EA modulators are ideal for this application since they can be used as optical switches and photodetectors due to their absorptive characteristic.

In consideration of the use of an EA modulator in OTDM drop and detect applications, several crosstalk issues need to be addressed. The electrical extinction ratio (defined as the ratio between the responsivity at high reverse bias and zero bias) has to be high enough to prevent absorption of the undropped channels that would interfere with the dropped channel. If a new channel is to be inserted in the available bit slot after a channel is dropped, it is also important to have a high optical extinction ratio to prevent interference between the dropped channel and the channel to be inserted.

To date, only the ability of an EA modulator to drop a channel without detection has been demonstrated [6]. In this paper, we demonstrate for the first time the use of an EA modulator to simultaneously demultiplex and detect the desired channel from an OTDM data stream while transmitting the other channel in an optically transparent manner.

II. Principle of Operation

The EA modulator used for the OTDM drop and detect application is a 2.5-μm-wide 300-μm-long device with traveling-wave electrodes as described in reference [7]. The 3-dB bandwidth was about 10 GHz when operated as a modulator at a reverse bias of -3 V and as a photodetector at -6 V (the traveling-wave electrode is terminated in 50 Ω). The maximum static optical and electrical extinction ratios are 40 dB and 28 dB, respectively, while the fiber-to-fiber insertion loss is 10 dB.

Fig. 1 shows the operation principle of the EA modulator for simultaneous drop and detection. The traveling-wave modulator is a four-port device; the optical input and output are shown as port 1 and 3, respectively. The EA modulator is biased at a high reverse bias and a 10-GHz driving signal is applied to port 2 using a high power amplifier. When the RF drive signal swings negative, the EA modulator is in the high absorption state and any optical signal passing through the modulator is absorbed and converted to photocurrent. On the other hand, when the RF signal swings positive, the EA modulator switches to high optical transparency with low absorption. Port 4 functions as the 10-Gb/s optical pulse detector. The output at this port consists of photogenerated carriers (if data "1" is present) as well as the attenuated 10-GHz driving RF signal. This signal is rejected from the data using a 6.4-GHz low-pass filter (with 60-dB attenuation at 10 GHz) and reflected back into the modulator synchronized with the original drive using an electrical phase shifter. The low-pass filter also converts the return-to-zero (RZ) data into nonreturn-to-zero (NRZ) format for bit-error-rate (BER) measurements. The alignment of the optical bits to the electrical drive signal is performed using an optical delay line. It is significant to mention that when the EA modulator operates as a

Manuscript received January 28, 2000; revised February 18, 2000. This work was supported by the Defense Advanced Research Projects Agency under the MOST program.

V. Kaman and J. E. Bowers are with the Department of Electrical and Computer Engineering, University of California-Santa Barbara, Santa Barbara, CA 93106 USA (e-mail: kaman@opto.ucsb.edu).

A. J. Keating was with the Department of Electrical and Computer Engineering, University of California-Santa Barbara, Santa Barbara, CA 93106 USA. He is now with Chromisys, Inc., Goleta, CA 93117 USA.

S. Z. Zhang was with the Department of Electrical and Computer Engineering, University of California-Santa Barbara, Santa Barbara, CA 93106 USA. He is now with Agilent Technologies, San Jose, CA 95131.

Publisher Item Identifier S 1041-1135(00)04630-9.

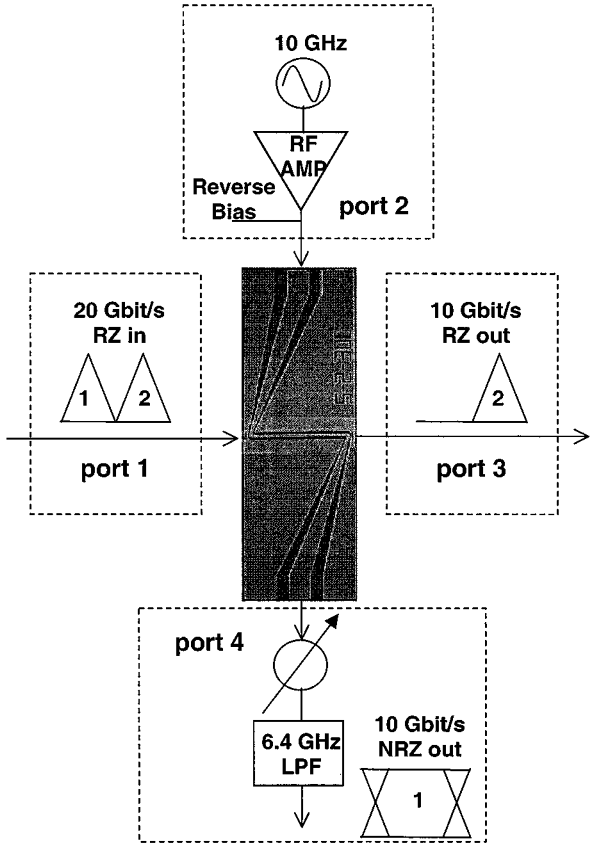

Fig. 1. Operation of the OTDM drop and detect experiment. Ports 1 and 3 are the optical input and output, respectively. Electrical RF drive is applied to port 2 while port 4 acts as the 10-Gb/s pulse detector.

photodetector, the output impedance of the high-power RF amplifier at port 2 acts as the termination. Since our drive amplifier had a low-frequency cutoff of about 10 MHz, this limited our experiment to a pseudorandom bit stream of $2^7 - 1$.

III. Experimental Set-Up and Results

The experimental setup for the 20-Gb/s OTDM simultaneous channel drop and detect is shown in Fig. 2. An EA modulator harmonically driven at 10 GHz was used to generate 11-ps pulses at 1555 nm. The 10-Gb/s data was encoded onto the 10-GHz pulse train by a $LiNbO_3$ modulator. The 10-Gb/s RZ data was then passively multiplexed (with 20 bits of delay between channels) to generate a 20-Gb/s OTDM data stream [Fig. 3(a)]. The 20-Gb/s signal of about 5 dBm was coupled into the drop and detect EA modulator using an optical preamplifier followed by a 0.6-nm bandwidth optical filter. A polarization controller was used at the input of the modulator for best operation. Fig. 3(b) shows the optical gating performed by the modulator at a bias of -5 V with the 10-GHz drive signal (10 V_{pp}) aligned to channel 2 for optical transparency. Fig. 3(c) shows the optical output at port 3, where channel 2 is transmitted, while channel 1 has been completely removed. The optically transparent channel 2 was then amplified before being detected at a commercial 10-Gb/s receiver. The simultaneously dropped and detected 10-Gb/s NRZ converted channel 1 is

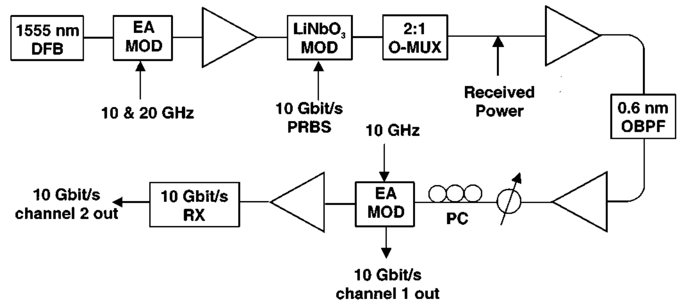

Fig. 2. Set-up for the 20-Gb/s OTDM drop and detect experiment (PC-polarization controller).

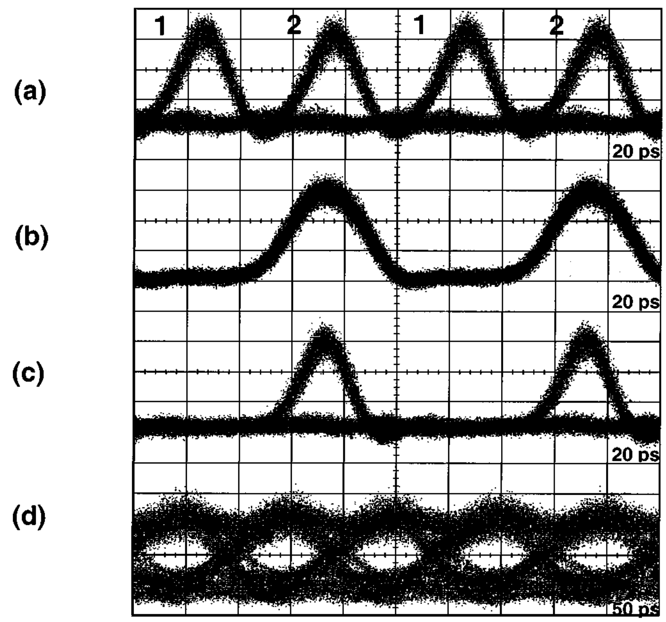

Fig. 3. Eye diagrams. (a) The 20-Gb/s OTDM data stream input to the EA modulator at port 1. (b) Optical transparency gating of the EA modulator aligned to channel 2. (c) The 10-Gb/s channel 2 transmitted in an optically transparent manner at port 3. (d) Simultaneously demultiplexed and O/E converted 10-Gb/s channel 1 at port 4.

shown in Fig. 3(d). Sufficient eye opening is achieved with most of the noise due to the residual absorption of channel 2.

Fig. 4 shows the BER measurements at 10 and 20 Gb/s, where the average received power was determined at the input of the optical preamplifier to the EA modulator for all measurements. Single-channel 10-Gb/s BER measurements were performed in order to determine the photodetection performance of the EA modulator by blocking one of the arms of the optical multiplexer. The reference line is when port 2 was terminated in 50 Ω and port 4 was as illustrated in Fig. 1 (the modulator was biased at -5 V). A receiver sensitivity of -31 dBm for a BER of 10^{-9} and a slight error floor is observed. It was determined that the error floor was due to the high-frequency limitations of the EA modulator at this bias; at a bias of -6 V, error-free operation and an improved sensitivity of -34 dBm was achieved (not shown). Next, the 50-Ω termination at port 2 was replaced by the driving amplifier with the RF signal applied to the EA modulator at a bias of -5 V. A negative penalty of 1 dB and error-free operation is observed. This improvement at -5 V is simply due to the higher reverse bias obtained from the negative swing of the

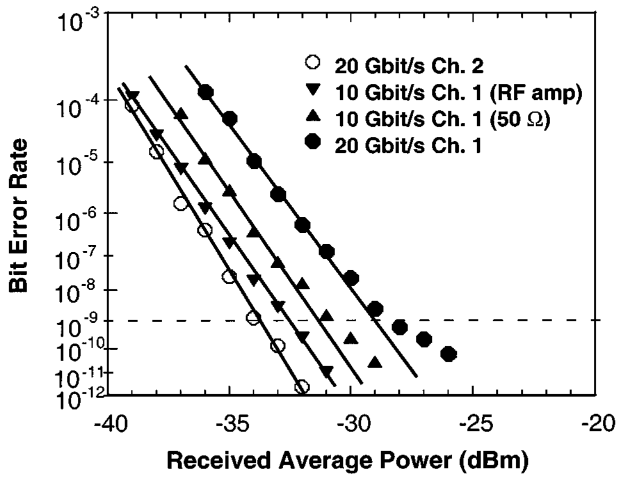

Fig. 4. BER curves for 10-Gb/s (triangles) and 20-Gb/s (circles) demultiplexing. The filled and open symbols correspond to the detected channel 1 and transparent channel 2, respectively.

10-GHz signal during the time period of the 10 Gb/s channel. However, it should also be mentioned that eye diagram deterioration was observed due to the high noise figure and imperfect output impedance of the driving amplifier.

20-Gb/s BER measurements were then performed with the EA modulator operated as a simultaneous demultiplexer and O/E converter at a bias of −5 V. The optically transparent channel 2 operated error-free with a 20-Gb/s sensitivity of −33.5 dBm and a 10-Gb/s sensitivity (when channel 1 was blocked) of −36.5 dBm (not shown). This result indicates the good optical extinction of the modulator as verified in the eye diagram [Fig. 3(c)]. On the other hand, the simultaneously dropped and detected channel 1 exhibited a 20-Gb/s sensitivity of −28.5 dBm and an error floor. From the single-channel 10-Gb/s sensitivity of −32 dBm, one can expect a 20-Gb/s sensitivity of −29 dBm for the same channel if there is no penalty. However, our measurements indicate that there is a power penalty of 0.5 dB and an error floor, which we attribute to the crosstalk from the residual absorption of channel 2. We believe that this penalty can be reduced with an EA modulator with sufficient bandwidth when operated as a photodetector at lower reverse biases. This would not only decrease the residual absorption, but also allow for a longer optical transparency window and a shorter detection window, which would be ideal for simultaneous demultiplexing and detection of a single channel from a four-channel 40-Gb/s OTDM data stream.

IV. Conclusion

In summary, we have demonstrated that a single component, the traveling-wave EA modulator, can be used to simultaneously demultiplex and detect a single channel from a bit-interleaved data stream, leaving the other channel unaffected. An error floor was incurred for the dropped channel due to residual absorption of the error-free transparent channel. We believe that this technique has the potential to realize a compact, high-speed full demultiplexing receiver (optical-serial to electrical-parallel conversion) by integrating a series of EA modulators on a single chip.

Acknowledgment

The authors would like to thank P. Abraham and Y.-J. Chiu for the material growth of the modulator, and B.-E. Olsson and D. Blumenthal for valuable discussions.

References

[1] M. Suzuki, H. Tanaka, K. Utaka, N. Edagawa, and Y. Matsushima, "Transform-limited 14-ps optical pulse generation with 15-GHz repetition rate by InGaAsP electroabsorption modulator," *Electron. Lett.*, vol. 28, pp. 1007–1008, 1992.

[2] M. Suzuki, H. Tanaka, and Y. Matsushima, "10 Gb/s optical demultiplexing and switching by sinusoidally driven InGaAsP electroabsorption modulators," *Electron. Lett.*, vol. 28, pp. 934–935, 1992.

[3] I. D. Phillips, A. Gloag, D. G. Moodie, N. J. Doran, I. Bennion, and A. D. Ellis, "Simultaneous two-channel OTDM demultiplexing using a single electroabsorption modulator in a novel bi-directional configuration," *Electron. Lett.*, vol. 33, pp. 1811–1812, 1997.

[4] T. Miyazaki, N. Edagawa, M. Suzuki, and S. Yamamoto, "Novel optical-regenerator using electroabsorption modulator," in *OFC'99 Tech. Dig.*, 1999, pp. 350–352.

[5] Y. Kisaka, A. Hirano, M. Yoneyama, and N. Shimizu, "Simple 2R repeater based on EA modulator directly driven by uni-travelling-carrier photodiode," *Electron. Lett.*, vol. 35, pp. 1016–1017, 1999.

[6] I. D. Phillips, A. Gloag, D. G. Moodie, N. J. Doran, I. Bennion, and A. D. Ellis, "Drop and insert multiplexing with simultaneous clock recovery using an electroabsorption modulator," *IEEE Photon. Technol. Lett.*, vol. 10, pp. 291–293, 1998.

[7] S. Z. Zhang, Y. Chiu, P. Abraham, and J. E. Bowers, "25-GHz polarization-insensitive electroabsorption modulators with traveling-wave electrodes," *IEEE Photon. Technol. Lett.*, vol. 11, pp. 191–193, 1999.