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A Novel Optical Cell Compressor for Optical Time Division Multiplexing System

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광 시분할 다중화 시스템을 위한 새로운 구조의 광셀 압축기

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ABSTRACT

A novel optical cell compressor for optical time division multiplexing system is presented. The compressor is capable of generating optically compressed very high bit-rate (possibly several tens of Gb/s) signals with minimum hardware. Contrast to the previously reported optical compressor, the compressor is mainly composed of passive optical devices and requires no synchronization among control signals in the process of compression, which results in simple implementation. We demonstrate a generation of optically compressed 6 Gb/s optical cells to confirm the fundamental operation of the compressor.

요 약

광 시분할 다중화 시스템을 위한 새로운 구조의 광셀 압축기를 개발하였다. 제안한 광압축기는 최소한의 하드웨어로 구성되어 있으며 수십 Gb/s 이상의 초고속으로 광압축된 신호를 생성할 수 있다. 기존의 발표된 광압축기와는 다르게 새로운 압축기는 주로 광 수동소자로 이루어졌으며 압축과정에서 제어신호간의 동기를 필요로 하지 않기 때문에 간단하게 구현할 수 있다. 제안한 광압축기의 기본적인 동작을 확인하기 위해 6 Gb/s로 압축된 광셀을 생성하였다.

I. Introduction

In realizing large capacity photonic system, various kinds of optical multiplexing have been studied. An optical time-division multiplexing (OTDM) scheme is one of the promising candidates of optical multiplexing based upon present technology [1]. A wavelength-division multiplexing (WDM) is also being studied eagerly in

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these days for its capacity of more than tens of teraherts bandwidth. However, to adopt WDM scheme in photonic system, many breakthroughs in various functional devices like sensitive wavelength tuners and tunable optical filters should be preceded [2]. In OTDM, a high bit-rate data stream is constructed directly by time-multiplexing several lower bit-rate optical streams. This approach to optical time-division multiplexing increases the bit rate of lightwave systems beyond the bandwidth capabilities of the drive electronics. A cell-interleaved multiplexed signal format is preferred to a bit-interleaved multiplexed signal format since multiplexity for bit-interleaved signal format is directly restricted by attainable switching speed of currently available optical switches. An optical compressor is the key element of the cell-interleaved optical time-division multiplexer. The intervals between optical short pulses from light source are compressed at the optical compressor. The multiplexity of cell-interleaved OTDM system directly depends on the degree of optical compression. Conventional method of optical compression [3], [4] requires more active devices like optical switches and modulators as the length of optical cell increases. Furthermore, they require exact synchronizations between optical switches, which is very hard to implement for ultra high speed signal like more than several tens of Gb/s.

In this paper, we introduce a novel optical compressor composed of minimum hardware with no synchronization required regardless of the length of the cell to be compressed. In Section II, we introduce the operation principle of the newly proposed compressor. In Section III, we compare the novel compressor with previously reported one in terms of amount of hardware and loss. We also provide a possible architecture of optical multiplexer which employs the compressor we proposed. In Section IV, we experimentally demonstrate a generation of optically compressed 6 Gb/s optical cells to confirm the fundamental operation of the compressor. Conclusions are given in Section V.

II. OPERATION PRINCIPLE

The configuration of the novel optical compressor is shown in Figure 1. The intervals of lower speed optical streams are compressed to generate very high speed optical cells. The optical compressor is composed of k pairs of optical fiber delay lines, (k+1) 2×2 optical couplers, and one electro-optic intensity modulator for 2^k-bit signal compression. The timing chart which shows the compression procedure of the novel optical compressor is shown in Figure 2. The 4-bit optical signal compression is shown for simple understanding of the scheme. The optical short pulses from light source travel through three 2×2 optical couplers and two pairs of optical fiber delay lines. At the first coupler, the input pulse divided by two comes out to two outputs. The optical fiber delay line

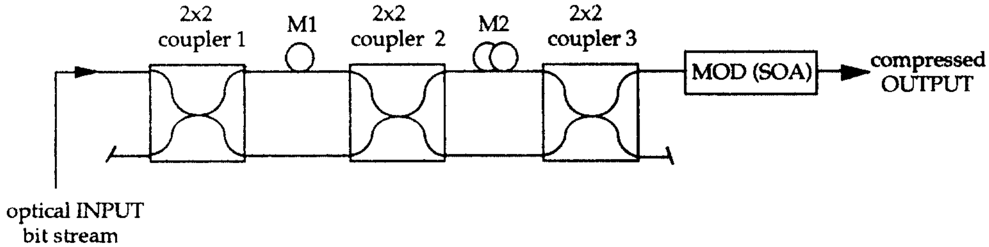

Fig. 1 Configuration of a novel optical compressor.

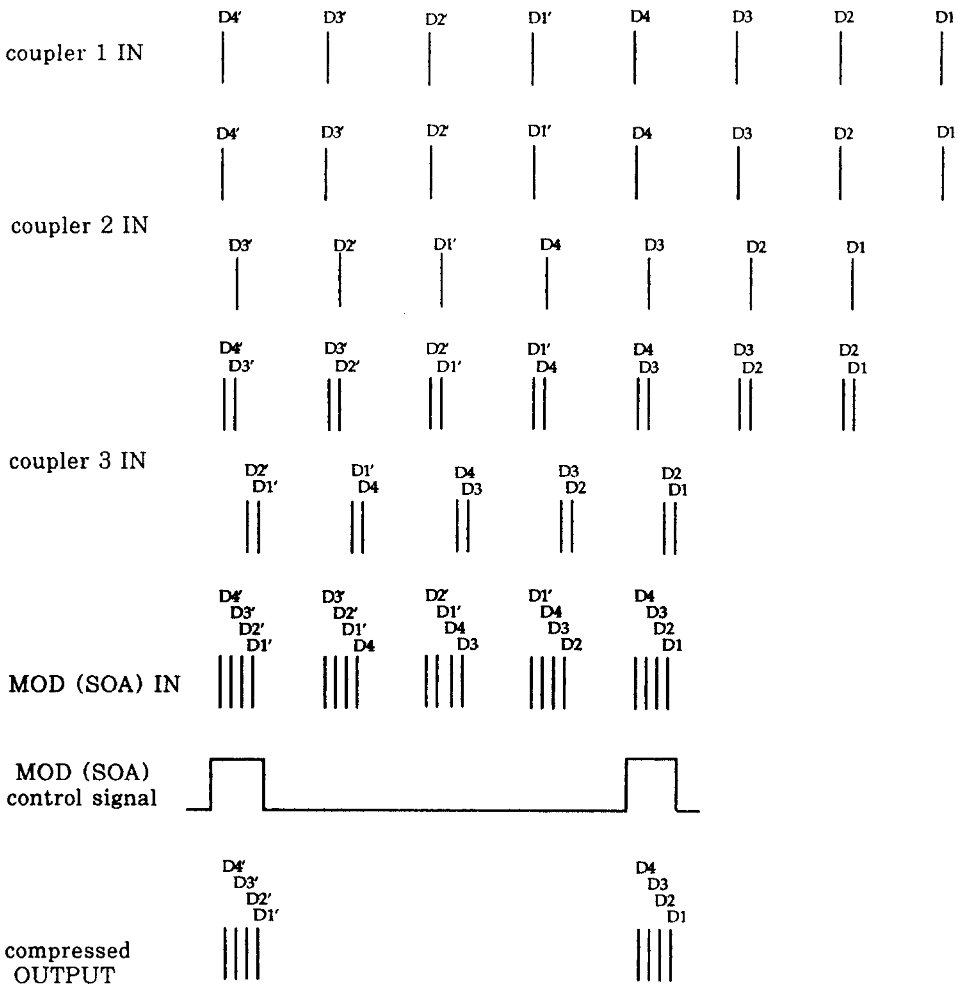

Fig. 2 Timing diagram of optical pulses in compressor.

pair gives the pulses a relative delay which depends on the degree of compression. For example, when 16 times of optical compression is needed, the optical fiber delay line pair M1 in Figure 1 should be designed to give relative delay of 15/16 period of the inverse of input data rate. Then the second coupler recombines the two pulses with compressed intervals, 1/16 period of inverse of data rate for above case. As a result, 2-bit pulses with compressed interval are two outputs from the second coupler. In turn, the next delay line pair gives the 2-bit pulses a relative delay, two times of the first delay, 30/16 period of the inverse of input data rate for above case. Then 4-bit compressed pulses are output from the third coupler. Three 4-bit compressed pulse stream comes into electro-optic modulator and only 4-bit compressed data with the same sequence of original one pass through. The 8-bit compressed cell can also be generated if the 4-bit compressed cells from two outputs of the third coupler travel through one more stage of optical delay lines and a 2×2 optical coupler.

Ⅲ. DISCUSSION

Since the compressor requires only one active component (electro-optic modulator) at the output regardless of the length of the data to be compressed, the difficulties of implementing the compressor is reduced significantly comparing with previous methods [3], [4]. Prucnal and Shimazu used active optical switch at each stage of compression instead of passive optical coupler in our scheme and therefore, their scheme requires exact synchronization among switches, which becomes major problem in implementing the compressor as the speed of signal increases. Therefore, as the length and the speed of signal increase, the advantage of our compressor is more enhanced. In compression of long bit signals, the accumulated optical power loss due to couplers will not be negligible. This optical loss can be compensated if the electro-optic modulator in the compressor is replaced by a semiconductor optical amplifier (SOA) which has a gating function as well as gain [5]. Table 1 shows the comparison of optical compression schemes in terms of number of optical components and amounts of control electronics required in the compression of 2^k-bit cell signals. Figure 3 shows the total optical loss in each compressor. Here, we assumed an insertion loss of active devices like optical switch or electrooptic modulator is 6 dB and an output of 3-dB fiber coupler is 3 dB down. Attenuation in the fiber

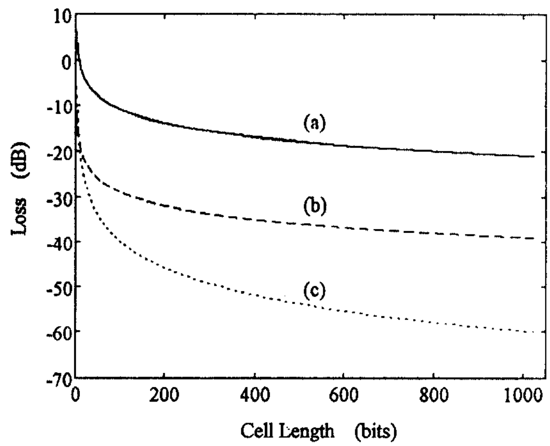

Fig. 3 Total optical loss in the compressor as a function of cell length
(a) Newly proposed scheme with SOA gating,
(b) Newly proposed scheme with EO-MOD gating,
(c) Previously reported scheme.

Table 1. Hardware comparison of optical compression schemes for the compression of 2^k-bit optical cell signals

	Newly proposed scheme (number of amounts needed)	Previous scheme [3], [4] (number of amounts needed)
Optical components		
• 2 × 2 optical switch	none	k
• optical fiber delay lines in pair	k	k
• 2 × 2 optical fiber coupler	k + 1	k
• electrooptic modulator OR semiconductor optical amplifier	always only one	none
Control electronics	requires only one comparatively low speed control electronics for EO-MOD or SOA gating regardless of the length of the cell to be compressed	requires k high speed control electronics with exact syncronization among them for optical switch control

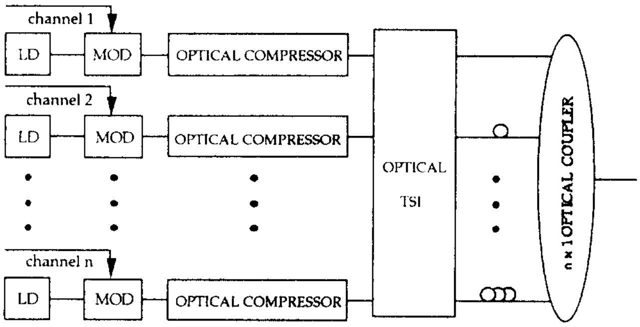

Fig. 4 Cell-interleaved optical time-division multiplxer.

delay lines and splicing loss are so small as to be neglected. The solid line indicates the loss of newly proposed method when SOA is used for output gating to select the right cells among useless cell streams. A fiber-to-fiber gain of SOA is assumed to be 12 dB. The dashed line shows the optical loss of the new compressor with electooptic modulator at the output. The dotted line is the result of previously reported scheme (Refereces [3] and [4]). As the length of cell increases, loss gap between new compressor and previous one gets bigger and bigger.

An optical multiplexer which employs this compressor for optical compression can be introduced. The configuration of the cell-interleaved optical time-division multiplexer is shown in Figure 4. The multiplexer is composed of optical short pulse compressor, optical space switch for time slot interchange (TSI), optical fibers for optical delay, and star coupler for compressed cell combining. Optical short pulses generated from gain-switched laser diode are modulated by an optical intensity modulator and comes into optical compressor. At the optical compressor, the intervals of lower speed optical streams are compressed to generate very high speed optical cells. By adjusting the degree of compression, a guard time can be inserted between compressed cells to move away high speed requirements of optical switch. After optical TSI, compressed cell signals experience relative time delay and combined at the star coupler. Optical fiber memories are used for relative time delay. The multiplexity of the multiplexer directly depends on the degree of optical compression. Since the optical compressor is the key component of the cell-interleaved optical time-division multiplexer, the advantage of the compressor (minimum hardware and simple implementation) exactly applies to the multiplxer.

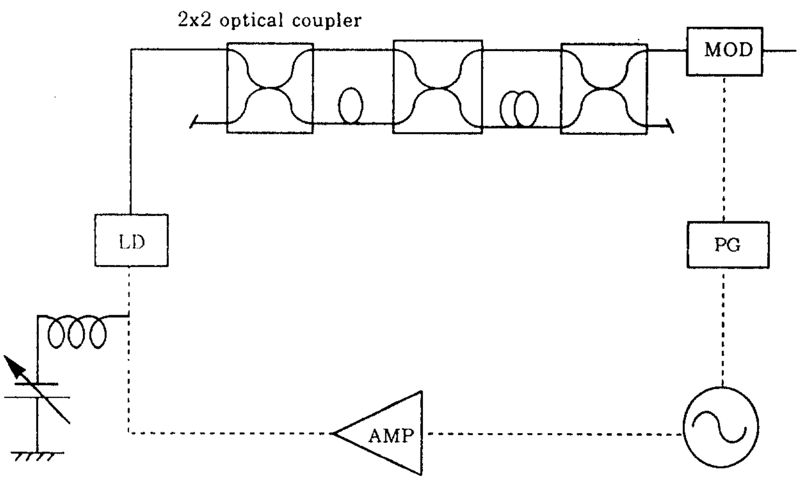

Fig. 5 Experimental configuration of the novel optical compressor.

Ⅳ. EXPERIMENT AND RESULTS

The experimental configuration of the novel optical compressor is shown in Figure 5. In this experiment, optical pulses generated from the gain-switched FP-LD (1.3μm) have a 1GHz repetition rate and a 80psec pulse width (FWHM). These pulses travel into three 2 × 2 optical coupler array and are compressed to 4-bit, 6 Gb/s optical cells. The degree of compression depends on the optical pulse width and optical delay lines between couplers. Much higher bit-rate compressed signals can be generated by employing ultrashort

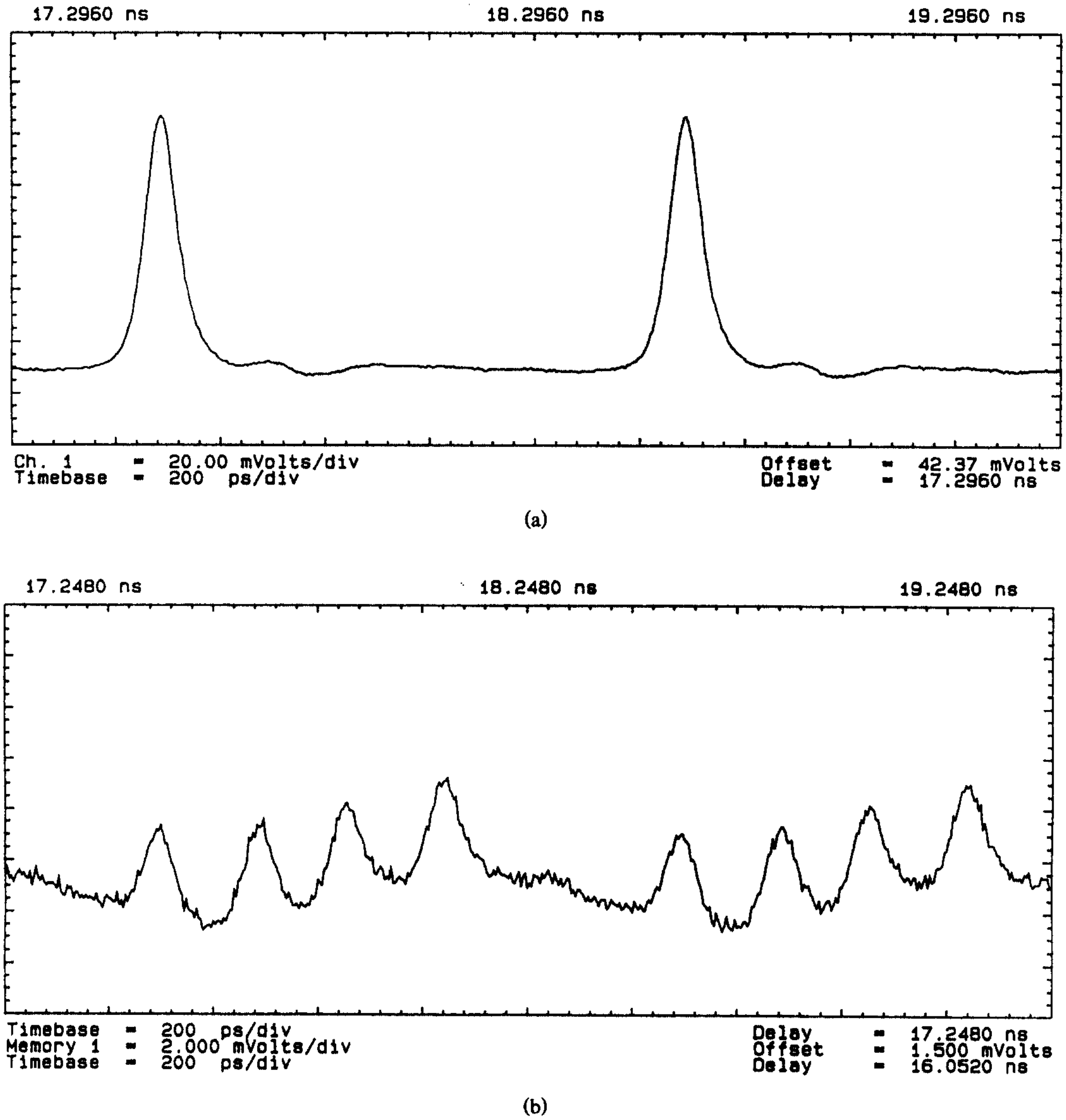

Fig. 6 Experimental results (a) Optical short pulses with 1GHz repetition rate and 80psec pulse width, (b) Optically compressed 4-bit, 6Gbps optical cells.

optical pulses and adjusting the length of fiber delay lines. Since the high speed optical modulator at the end of compressor was not available at the time of experiment, the right sequence data picking procedure was omitted in this experiment. The experimental result is shown in Figure 6. The result is optically compressed 4bit, 6 Gb/s optical cells. The amplitude of compressed optical signals tends to decrease as the optical signals pass through optical delays due to splicing losses. The generation of optically multiplexed mutigigabit/s optical cells from cell-interleaved optical time-division multiplexer will be demonstrated as the high speed optical components become available. Also, in the future, longer optical cells with higher bit-rate can be generated by introducing optical ultrashort pulses [6] and semiconductor optical amplifier for the replacement of electro-optic modulator in the compressor.

V. CONCLUSION

In this paper, we provide a novel optical compressor for OTDM system. The newly proposed compressor is composed of minimum hardware regardless of the length of the cell to be compressed. It also requires no synchronization among control signals. Contrast to the previously reported optical compressor, the compressor is mainly composed of passive optical devices, which relieves the speed limitation of control electronics as the rate of compression increases. In the experiment, we demonstrate a generation of compressed 4bit, 6 Gb/s optical cells to confirm the fundamental operation of the compressor. With its minimal hardware and its capacity of multiplexing several tens of Gb/s data, this novel optical compressor has a great potential in the photonic time-division multiplexing systems.

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