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An optical packet compressor for a feasible all optical inter-LAN TDM network

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Abstract. We demonstrate an optical packet compressor based on a fiber delay loop. Using the fabricated compressor, 25-MHz 10-bit packet was compressed to 5 GHz.

1. Introduction

Remarkable progress in transmission rate of optical time-division multiplexed (OTDM) signals in fibers now allows transmission of data beyond 100 Gbit/s over more than 100 km[1]. Such high speed transmission technology should be applied to next-generation optical network systems[2, 3]. Recently, the authors proposed a new OTDM network scheme[4] for connecting local area networks (LAN) using optical rate converters. In the proposed scheme, ultra-high speed OTDM network can be fully operatable by the use of currently available electro-optic switches by sacrificing approximately ten percent of the transmission speed. Optical rate converters using packet compressor and expander based on a delay loop were also proposed. In this manuscript, we focus on to the optical packet compressor and describe the compression characteristics. Compared to the packet compressor based on optical delay lines[5], the present scheme has the advantage in that the number of devices required is reduced and only one delay line adjustment is necessary to obtain the desired compression ratio. In section 2, we describe the configuration and operation of the packet compressor. In the compressor based on a fiber loop, ASE accumulation during compression operation should take considered. In section 3, we estimate the optical signal-to-noise ratio of the comprssed packet. In section 4, we describe experimental results of the fabricated compressor. Finally, we conclude in section 5.

2. Configuration of the packet compressor

The schematic view of the proposed packet compressor is shown in Fig. 1. The packet compressor is constructed by a delay loop which includes a 2 x 2 optical switch (SW1), an optical amplifier (OA), a delay line (DL) and an optical bandpass filter (OBPF), and another optical switch (SW2). The delay loop may be constructed by fiber-pigtailed devices or solely constructed on a guided-wave device. The loop length is adjusted by DL so that when the first input bit goes around the loop and advances further a distance corresponds to one output bit period, the next bit arrives and coupled in to the loop. The switching ratio of SW1 should be adjusted to maximize signal-to-noise ratio of the compressed output packet as discussed in section 3. Fig. 2 shows a timing chart of the compression operation of an N-bit optical packet, where bit rates of input and output packets are $1/T_{in}$ and $1/T_{out}$, respectively. In this scheme, the maximum number of bits which are to be compressed is limited by the packet compression ratio T_{in}/T_{out}. Nevertheless, the packet length can be made longer when another compressor is cascaded to the first one.

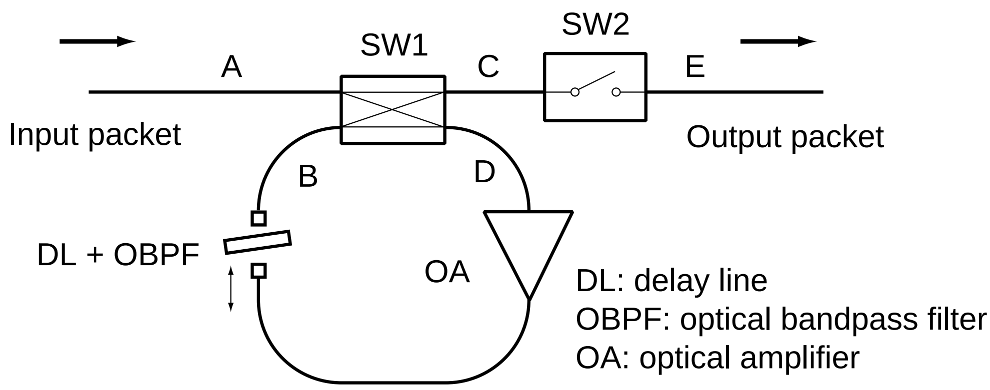

Fig. 1 The schematic view of the proposed optical packet compressor.

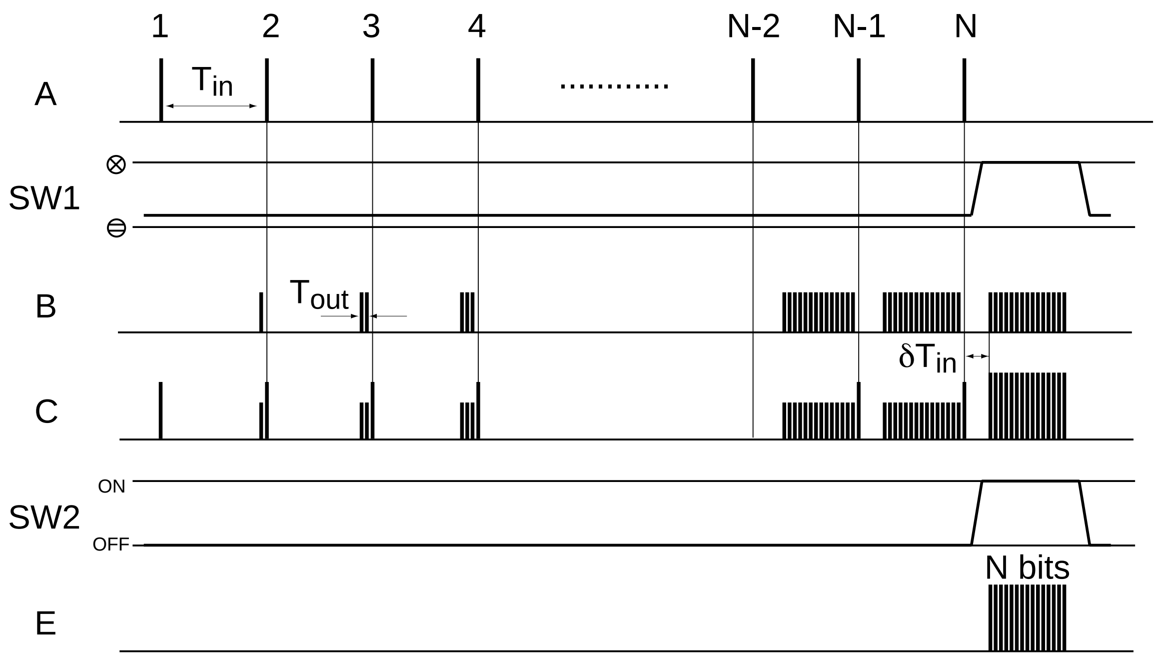

Fig. 2 Timing chart of compression operation of an N-bit optical packet.

3. Estimation of ASE noise accumulation

In this section, we estimate optical signal-to-noise ratio (OSNR) of the output optical packet. Let us denote that the insertion losses of SW1 between A and D, B and C, the insertion loss of DL and OBPF, and the gain of OA, as α_{in}, α_{out}, α_f and G. The average power in a bit period of output optical packet P_{out} is obtained as the following equation

$$P_{out} = P_{in}\alpha_{in}\eta G\alpha_f\alpha_{out}, \qquad (1)$$

where P_{in} and η are average powers in a bit period of input packet and coupling ratio of the SW1 during compression operation, respectively. The spectral density of ASE included in the output is obtained as following

$$S_{ASE} = h\nu n_{sp}(G-1)\alpha_f \alpha_{out}(N+1) \tag{2}$$

where h, ν, n_{sp} and N are the Planck's constant, optical carrier frequency, spontaneous emission factor of the OA, and the number of compressed bits, respectively. The OSNR of the output at the carrier frequency is then obtained as following

$$OSNR = \frac{P_{out}}{S_{ASE}\Delta\nu} = \frac{2\alpha_{in}\eta}{h\nu\Delta\nu NF(N+1)}P_{in}, \tag{3}$$

where NF is the noise figure of the OA. Note that we used the relationship $NF = 2\, n_{sp}(G - 1)/G$ so as to consider the signal-spontaneous emission beat noise only. From the eq. (3), one can find that the OSNR is maximized when η of the SW1 is 1 which corresponds to 'cross' state. However, required G becomes infinite when η =1. Also higher gain of optical amplifiers usually results in higher NF if there is no special scheme to reduce NF. Thus, there should exist an optimum value in η to maximize OSNR of the output packet according to the configuration of the OA. Fig. 3 shows calculated OSNR versus N, where α_{in} = 4 dB, NF = 5 dB, P_{in} = 2 mW, $\Delta\nu$ = 125 GHz (1 nm) and the wavelength of 1.55 μm. As shown in the figure, OSNR of more than 25 dB can be obtained when N < 100.

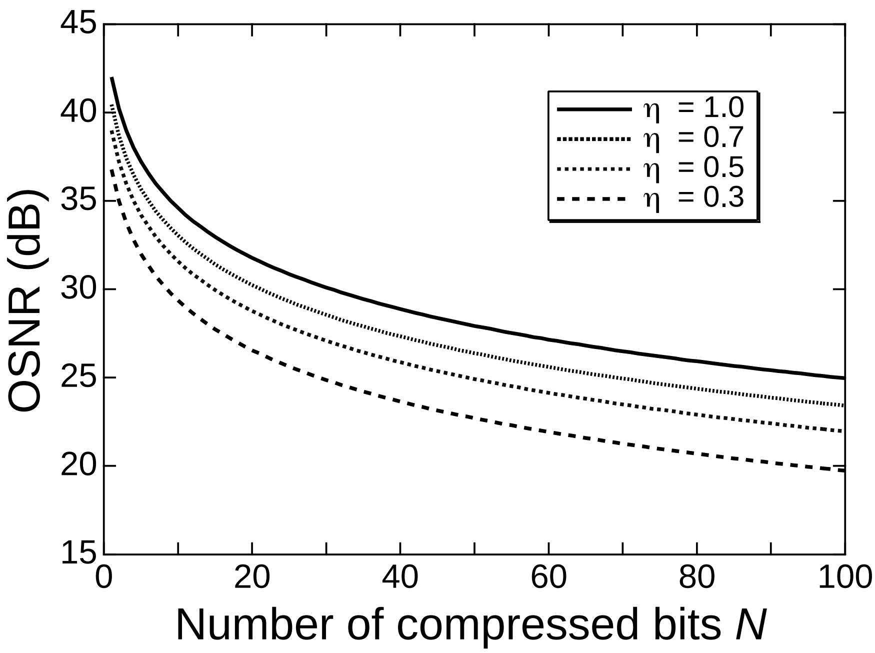

Fig. 3 Calculated optical signal-to-noise ratio of output packet with 1 nm bandwidth versus number of compressed bits N.

4. Experiment

Fig. 4 shows the experimental setup. A 25-MHz, 1-ps fiber laser was used as an optical pulse source. The generated optical pulses were switched by a $LiNbO_3$ optical switch SW1 to form N bit packet (for simplicity, all '1's) and guard time of X bits. The guard time is necessary to ensure

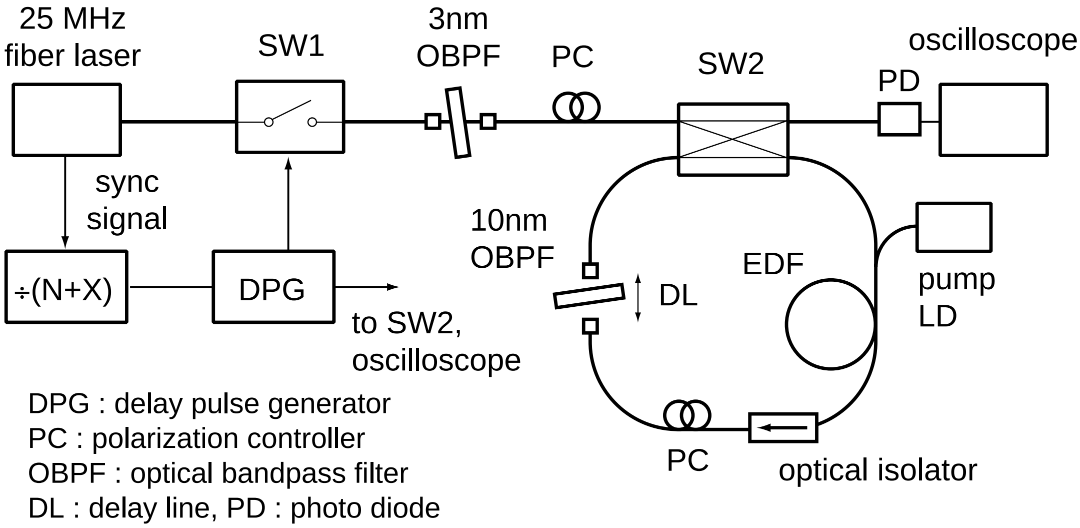

Fig. 4 Experimental setup.

complete clearing the fiber loop after compression because the extinction ratio of SW2 is not infinite. 25-MHz synchronized signal from the fiber laser was frequency divided by (N + X) to generate timing control signals for SW1, SW2 and triggering an oscilloscope. The fiber loop was constructed by a 2 x 2 $LiNbO_3$ optical switch (SW2), erbium-doped fiber (EDF), a polarization controller (PC), a 10-nm optical bandpass filter (OBPF) and a delay line (DL). Because the repetition frequency of the input packet is 25 MHz, the loop length is approximately 8 m. In this experiment, we designed the fiber loop to compress the incoming 25 Mbit/s packet to 5 Gbit/s. The loop length adjustment was done as following. First, we turned off the fiber laser source and drove SW2 by a sine wave of a function generator. When the pump power of the EDFA is increased and the frequency of the generator is a certain value, the fiber loop starts mode locking and generates optical pulses. Fig. 5 shows an example of the generated pulses. In this case, the frequency of the generator is half of the fundamental mode-locking frequency to perform rational mode locking[6, 7]. By comparing the repetition frequencies of the generated pulses and the fiber laser source, the correction length of the loop for proper compression operation can be calculated. After the rough adjustment of the loop length, precise adjustment was made with DL.

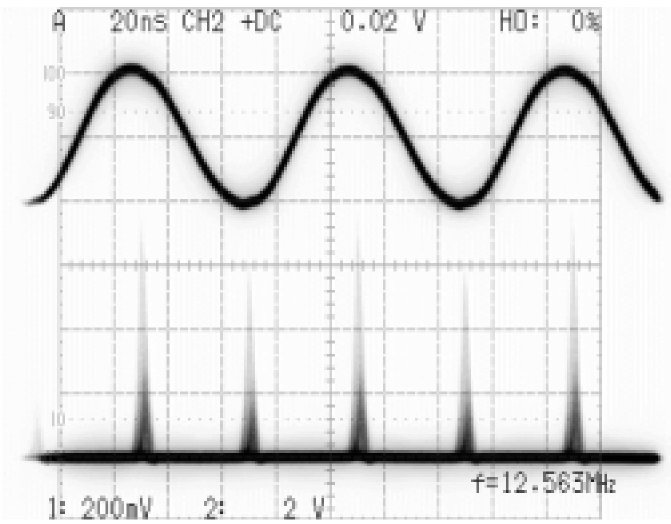

Fig. 5 Generated optical pulses by rational mode locking of the fiber loop for loop length adjustment.

In the packet compression experiment, we set the number of compressed bits N to 10. The pump power of the EDFA was adjusted to obtain proper gain to compensate the loop loss. Fig. 6 shows the output signals, which corresponds to C in Fig. 2, observed with a 500-MHz-bandwidth analogue oscilloscope. Eleven pulses can be seen in the figure whose repetition frequency corresponds to that of the fiber laser source. The first ten pulses are the packets which corresponding to time 1, 2, 3, … at C of Fig. 2, and the last pulse is the packet which are compressed to 5 Gbit/s. The noise level at the compressed packet is slightly increased due to ASE noise accumulation. Fig. 7 shows the observed waveform of the compressed packet. Due to timing jitter of the frequency divider, we observed the waveform in average mode. 10 bit pulses with the repetition of 5 GHz are clearly seen in the figure.

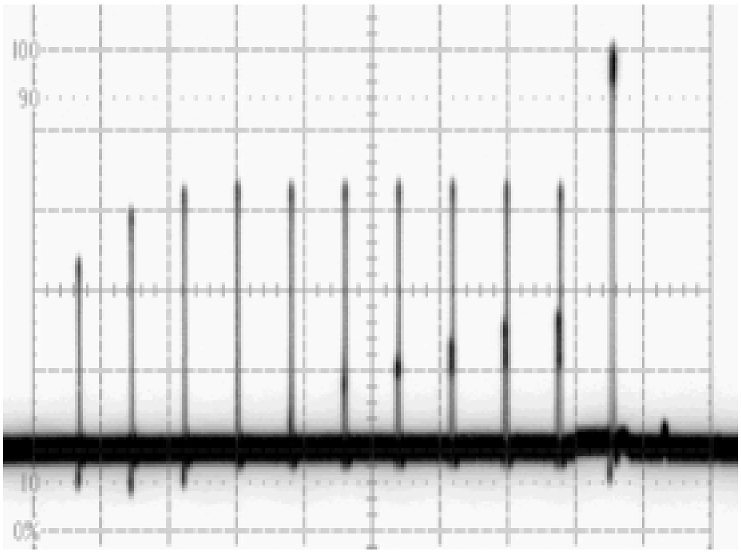

Fig. 6 Output signals, which corresponds to C in Fig. 2, observed with an analogue oscilloscope (50 ns/div).

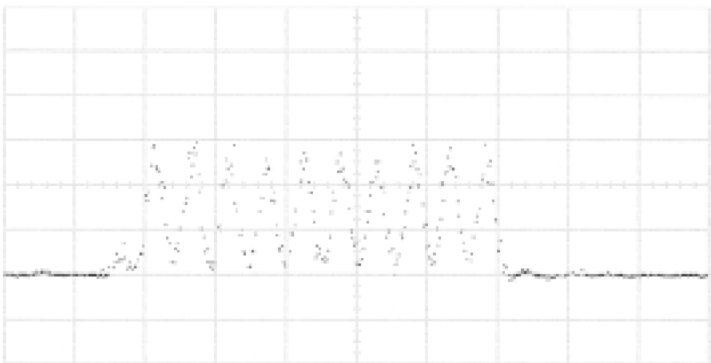

Fig. 7 Observed waveform of the compressed 10 bit packet (400 ps/div).

5. Conclusion

We demonstrated a simple optical packet compressor using a fiber delay loop for a feasible all optical inter-LAN TDM network. The calculated optical SNR of the compressed packet exceeds 25 dB when number of compressed bits is less than 100. Using the fabricated compressor, 25-

MHz 10-bit packet was successfully compressed to 5 GHz. Future work includes increase of the number of compressed bits and the measurement of optical SNR of the compressed packet.

Acknowledgements

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