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Performance of a 4 × 10 Gbit/s optical time domain multiplexed system using SMZ switching

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Abstract

Optical time division multiplexing (OTDM) is emerging and promising alternative for future high-speed photonic networks because of its ability to accommodate higher bit rate and flexible bandwidth. Among other factors the performance of an OTDM system largely depends upon the switching characteristics of a de-multiplexer (DEMUX). Symmetric Mach–Zehnder (SMZ) have been found to be most suitable than all the available de-multiplexing switches because of compact size, thermal stability, and low power operation. In this paper, we simulate four-channel OTDM systems (all channel multiplexer (MUX) and DEMUX) with a Mach–Zehnder modulator and SMZ DEMUX to investigate the impact of signal power, pulse width and control signal power on BER.

Keywords: OTDM; Control signal power (P_{control}); Pulse width and signal power (P_{signal})

1. Introduction

Extensive research has been carried out over the years in developing practical optical time division multiplexing (OTDM) systems considering its vast potential in future high-speed photonic networks [1–5]. They have used periodically poled lithium niobate (PPLN) hybrid integrated with planer light wave circuit (PLC) for multiplexing of different channels and studied an all channel multiplexer (MUX) and de-multiplexer (DEMUX) systems. Morari et al. [6] presented a new technique electro-absorption modulator as MUX and DEMUX with phase locked loop (PLL) clock recovery. Over the years, it was understood that the performance of an OTDM System largely depends upon the switching characteristics of a DEMUX and therefore extensive study has been done on the performance of various de-multiplexing switches [7–9,13–17]. Important characteristics of optical switches include extinction ratio, insertion loss, crosstalk, and switching time. The performance of optical switches is compared on basis of these parameters. Investigations revealed that among all the switches symmetric Mach–Zehnder (SMZ) were found to be most suitable because of compact size, thermal stability, and low power operation analysis [10]. It was also outlined that SMZ has symmetric switching window and hence it is less venerable to jitter. The main

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advantage of SMZ structure over other interferometric switches like terahertz optical asymmetric de-multiplexer (TOAD) is that SMZ can be easily integrated on to a single photonic chip [11,12]. Presently, crosstalk suppression in all optical SMZ has gained importance. A study in this regard was presented in the year 2005 [18], in which the crosstalk suppression was achieved using two unequal control pulses. This study has been accomplished using virtual photonic simulation package (VPI) and involves a MUX and a DEMUX. But the fiber length over which the signal has to be propagated is missing. This in itself is a serious drawback, since without an optical fiber; the system fails to be a practical OTDM system.

It is important to mention that OTDM is a time synchronized system and proper signal recovery cannot be achieved without synchronization between the transmitter and the receiver. Inclusion of optical fiber would involve a time delay incurred due to propagation of the signal over the fiber. It would also involve all-important issues like dispersion and fiber nonlinearities. In order to design an optimistic system, the time delay due to the fiber length has to be taken into account. Only then it is possible to establish time synchronization between the transmitter and the receiver. The issues of dispersion, fiber nonlinearities and power penalty to achieve a desirable BER, have to be settled in order to achieve optimum performance.

This paper presents OTDM system, which is simple, involving low power, and one which has the superiority of de-multiplexing with a SMZ switch and investigated the impact of signal power, pulse width and control signal power on BER. This system involves an all channel independent MUX, propagation on a fiber of given length and an all channel DEMUX.

2. System description

The transmitter comprises of a pseudo-random binary sequence or PRBS generator, mode locked laser diode, an electrical generator, four time shifting blocks, an optical MUX and an optical normalizer. Multiple channels from a MLLD are RZ modulated with a different PRBS patterns. The PRBS block generates multiple pattern outputs, each different from the other and at same bit rate. All the channels from MLLD are at same wave length of 1550 nm and of same power. Before being multiplexed together each consequent channel is delayed by 1/4 of time window in succession. Total power of all the channels is controlled by an optical normalizer, which determines the average output power of OTDM signal before propagation over the fiber length. The OTDM signal travels over optical fiber of 75 km length and then it is de-multiplexed at the receiver end.

The receiver consists of four identical SMZ DEMUXs (but with different time delays), each consists of a pulse train generator (with same repetition rate as the transmitter), optical normalizer block, pulse splitter and two time delay blocks and an SMZ switch with two output ports. The BER meter is connected at both output and reflected port to get the results. All the SMZ DEMUXs are connected at the output of the nonlinear fiber. In Fig. 1 only one such DEMUX has been shown to explain the basic set up.

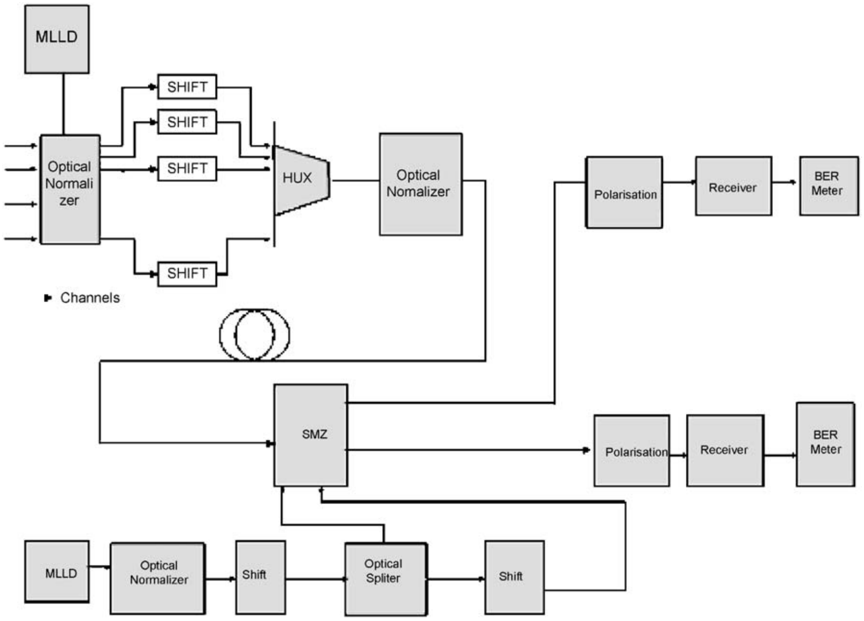

Fig. 1. Simulation model.

3. Results and discussion

Synchronization between transmitter and receiver in OTDM is a critical issue for optimum performance of system. In this paper, the transmitter and the receiver has been synchronized by the addition of optical delay in the control signal. The optical delay is varied as an integer multiple of 1/4 of the pulse width within an expected bound. The pattern that emerges from such variation determines the optimum optical delay required for each channel.

The effect of noise and distortion are well known in digital transmission. Noise causes bit errors at the decision gate of the receiver and distortion causes changes to the pulse shapes resulting in inter symbol interferences (ISI), which also produces bit errors. The major parameter in addition to bandwidth, which characterizes a digital optical link, is BER. So the effect of signal power (P_{signal}), control signals power (P_{control}), and pulse width on BER is investigated.

Fig. 2 shows variation of BER with change in signal power. As mentioned previously optical normalizer controls the average output power of the multiplexed signal. The BER for channel 1 is in the range of $10^{-8.75}$–10^{-28} for P_{signal} values 5 and 9 dBm, respectively. So it is observed that with the increase in signal power (P_{signal}) the BER is improved. Similarly for channels 2 and 4 this variation is in the range of $10^{-8.75}$–10^{-31} and $10^{-8.5}$–10^{-21} for P_{signal} values of 5 and 9 dBm, respectively. It is interesting to note that BER for channels 2 and 3 is same for all the P_{signal} values. BER of an optical receiver is inversely proportional to SNR, which is in turn dependent on optical power of the signal. Thus BER decreases with increase in signal power.

Further in Fig. 3 the effect of change in pulse width on BER is investigated. The pulse width of the input signal was varied within the bounds of $5e^{-12}$–$7e^{-12}$ m and variation in BER was observed. As seen in the figure for channel 1 BER at $5e^{-12}$ m is 10^{-27} and with increase in pulse width it decreases to 10^{-37} for pulse width $7e^{-12}$ m. Once again there is an overlap in curves for channels 2and 3 and the variation for BER is from 10^{-33} to 10^{-97} for above-mentioned variation in pulse width. For channel 4 the value of BER varies from 10^{-22} to 10^{-31} for above-mentioned variation in pulse width. The results indicate an improvement in receiver performance with increase in pulse width. This improvement can be attributed to reduction in pulse width distortion.

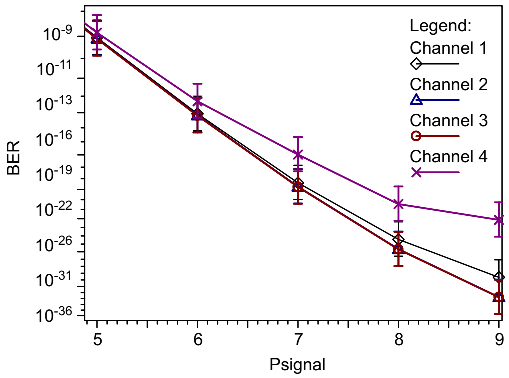

Fig. 2. BER versus input signal power with dispersion.

It must be understood that control signal power has a significant effect on the performance of an SMZ. Thus, investigation of receiver performance with variation of control signal power must be one of the core issues. Fig. 4 shows a significant degradation in receiver performance when control signal power is increased gradually beyond 22 dBm. Thus in case of channel 1 BER at 22 dBm control signal is 10^{-28} and increases to 10^{-4} at 26 dBm. Channels 2 and 3 once again exhibit identical BER patterns and variation is in the range of 10^{-34}–10^{-8} at 22 and 26 dbm, respectively. The variation in BER for channel 4 is in the range of 10^{-22}–10^{-2} for the above-mentioned variations in control signal power. It is understood that principle of operations of an SMZ is based on interference between signals passing through the two legs of an SMZ.

The control signal affects a change in refractive index of semi-conductor material. The change in refractive index in turn introduces a phase shift in the input signal.

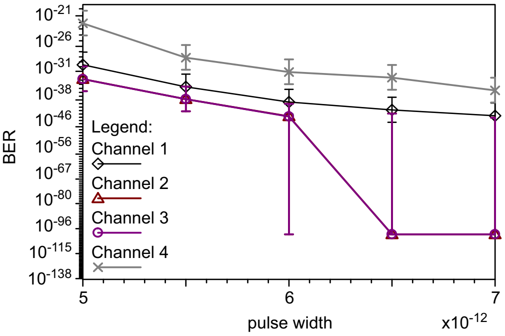

Fig. 3. BER versus pulse width with dispersion.

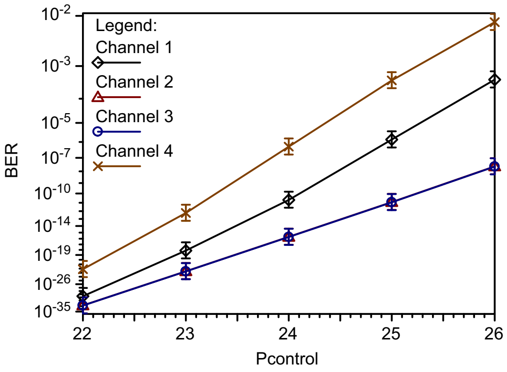

Fig. 4. BER versus power control signal with dispersion.

The two signals interference at the output and the resultant output is dependent on their relative phase shifts. Thus, the signals may interfere either constructively or destructively. From the graphs it is evident that an increase in control signal beyond 22 dBm introduces a phase shift, which degrades the receiver performance and BER goes on increasing with increases in control signal power. Fig. 5 depicts eye diagrams for channel1, at P_{control} values of 22 and 26, respectively. There is degradation in decision level offset values from 1.5×10^{-5} to 7×10^{-6} with increase in P_{control} values from 22 to 26. This observation supports the conclusion drawn from BER verses P_{control} signal.

Fig. 6 shows the effect of P_{control} on BER with no dispersion for all the channels. It is evident that dispersion effects receiver performance in a significant manner. The bit error rate is considerably low without dispersion. From Figs. 4 and 6 it is observed that for channel 1 BER decreases from 10^{-28} to 10^{-105} with and without dispersion, respectively, at control signal power of 22 dBm. BER decreases from 10^{-4} to 10^{-17} with and without dispersion at control signal power of 26 dBm. Similarly, for channels 2and 3 BER decreases from 10^{-34} to10^{-105} and 10^{-8} to 10^{-19} at 22 and 26 dBm control signal power with and without dispersion, respectively. In case of channel 4 the decrease in BER ranges from 10^{-22} to 10^{-105} with and without dispersion at 22 dBm control signal power and decrease is in the range of 10^{-2} with dispersion to 10^{-12} without dispersion for 26 dBm. Therefore it is concluded that the performance of OTDM system can be improved using dispersion compensation fiber.

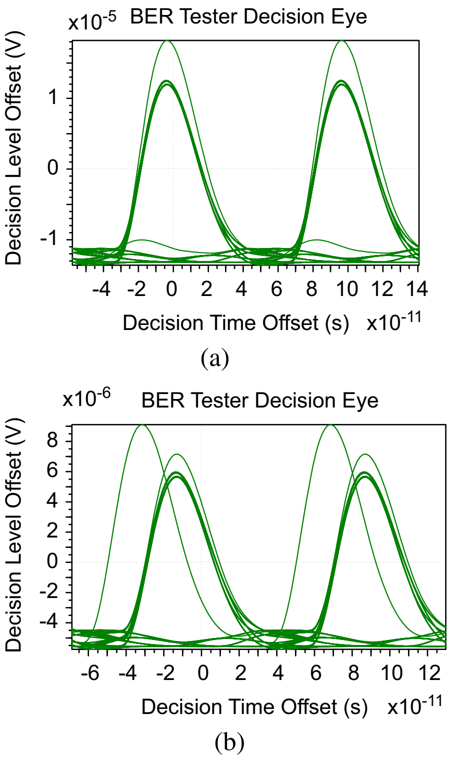

Fig. 5. Eye diagrams for channel 1: (a) at P_{control} 22 and (b) 26, respectively.

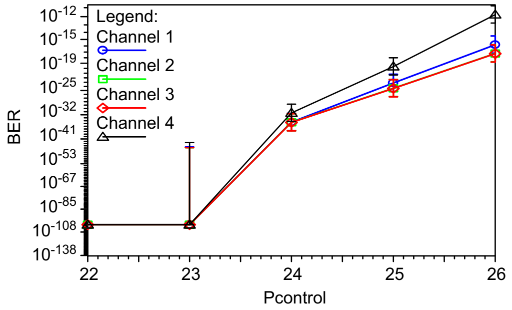

Fig. 6. BER versus power control signal without dispersion.

4. Conclusion

Four-channel 4×10 Gbs OTDM system (all channel MUX and DEMUX) with a Mach–Zehnder modulator, SMZ DEMUX and a fiber length of 75 km, has been successfully demonstrated. Investigations reveal that BER decreases with increase in signal power and increase in pulse width. Further BER increases with increase in control signal power and due to dispersion in single mode fiber.

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