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An80 Gb/s HybridOptical Time Division Multiplexing System with Enhanced Tolerance to De-multiplexing Misalignment

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Abstract—we propose a novel eight-channel hybrid optical time domain multiplexing (OTDM) system. Each channel capacity is 10.61 Gbps and four channels of optical return-to-zero (RZ) on-off-keying (OOK) interleavedwith other four return-to-zero (RZ) differential phase-shift-keying (DPSK) channels. Our scheme can offer much-enhanced tolerance against timing misalignment in OTDM de-multiplexing, as compared with the conventional OTDM system having homogeneous modulation format. We used TOAD (Tera-hertz Optical Asymmetric De-multiplexer) device to configure de-multiplexer of theOTDM system. A 1-dB tolerance of timing misalignment was around 15 ps for both signal formats. The simulated result shows an average BER 8.7651e-010 for RZ-ASK and BER 4.8642e-010 for RZ-DPSK at received power ~17dBm at receiver.

Keywords—*Optical time division multiplexing (OTDM); Return-to-zero differential phase shift keying (RZ-DPSK); Return-to-zero on off keying (RZ-OOK); Semiconductor optical amplifier (SOA); terahertz optical asymmetric de-multiplexer (TOAD).*

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I. INTRODUCTION

In recent years demands of bandwidth are increasing rapidly hence passive optical networks is the only solution to this problem. The optical time division multiplexing (OTDM) is an effective approach to up-grade the capacity of each channel in optical system [1-3]. At transmitter end,lower-speed data streams are multiplexed optically into higher-speed streams, and at the receiver end the lower data stream can be extracted from higher speed stream using the de-multiplexing unit. The optical TDM and EletronicsTDM are functionally the same. The main diffrence is that in OTDM, all the operations such as multiplexing and demultiplexing are performed at highspeed and OTDM can support the aggregate rate in the order of 100 Gb/s. The optical low speed bit stream that is generated from different sources are interleaved in time and produce the single high speed data stream [4].

Different configurations of fiber-based interferometric switches were proposed for channel de-multiplexing in OTDM systems. One of such configurations is so called Terahertz Optical Asymmetric De-multiplexer (TOAD) device, first proposed by P. Prucnal [5], which uses the semiconductor optical amplifier (SOA) as a nonlinear switching element and TOAD device is based on Sagnag interferometer (also referred as nonlinear optical loop mirror - NOLM) in its original configuration.The incoming data signal enter the fiber loop and passes through SOA at different time and recombine at 50/50 coupler interferometrically at the base of the loop. Since signals propagating around the loop in both directions (i.e.see the same medium), the data is reflected back toward the source. The switchingoccurs in the presence of the control signal. The power is high enough, chosen the 10 time of the pulse energy when the signal is injected into the loop. SOA gets saturaes and index of refrectionischanses. Resulting at the output port , a differential phase shift can be achieved between the two counter-propagating data pulses to switch the data pulses.The semiconductor optical amplifier (SOA)is offset from the center position of the fiber loop and this offset will provide switching window duration [6-8]. The two control pulse has time delay equal to duration of switching window, i.e.TDM channel width in DEMUX applications.

II. SIMULATION SETUP AND RESULTS

The simulation setup topology is shown in Fig. 1. A semi-conductor mode-locked laser diode (MLLD) generated an optical pulse train (pulse width of about 1.5 ps full width at half maximum (FWHM) peak to extinction ratio > 20dB) at a repetition rate of 10.61 Gb/s at wavelength of 1550 nm is separated into two branches. In one branch a data pattern of (2^{31}-1) is generated by a pseudorandom bit sequence (PRBS) generator fed to the Mach-Zehnder modulator (MZM) to generate return-to-zero on-off-keying (RZ-OOK) signal format. Optical pulse of 1.5 ps corresponds to data bit 1 and 0 for no optical pulse. Similarly a phase modulator (PM) with 180 degree phase shift is used in place of MZM to obtain a return-to-zero differential phase shift keying

(RZ-DPSK) signal format. Optical pulse of 1.5 ps corresponds to data bit 1 and 0 both. Each optical pulse is at a phase shift of 180 degree. The multiplexed format of RZ-OOK

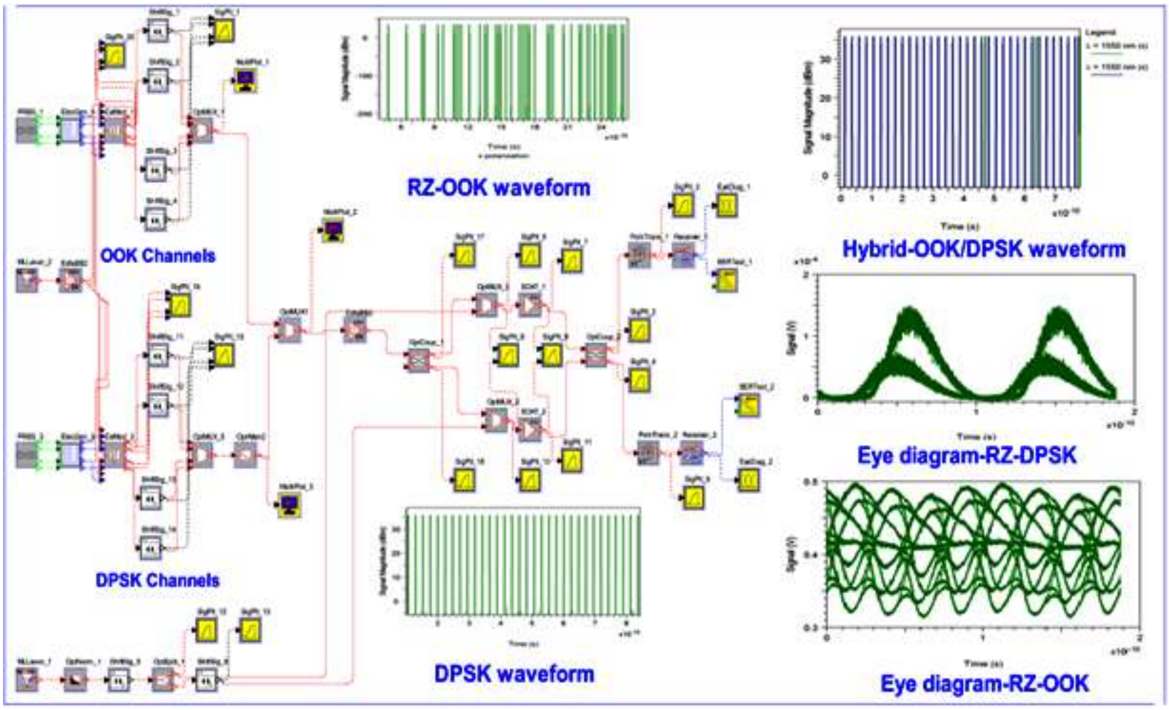

Fig. 1.Simulation setup topology of hybrid OTDM system

and RZ-DPSK is known as hybrid RZ-OOK/DPSK and waveform is shown in figure 1.

Before being multiplexed together each consequent channel is delayed by 11.7 ps (1/8 of the time windowi.e. 94.3 ps). Total power of all channels is set to -12 dBm.Next, the control signal consists of pulse train generator with 10.61 GHz repetition rate, pulse splitter, and two time delay blocks. The first time delay block will set the control signal to de-multiplex the channel (e.g. time delay is zero if channel 1 to be multiplexed, time delay is 11.7 ps if channel 2 to be de-multiplexed, and so on).

Control signal split in two parts before being coupled with data signal in two arms of symmetric Mach-Zehnder (SMZ) Interferometer [9]. The second time delay block sets switching window duration and is set to data pulse duration,

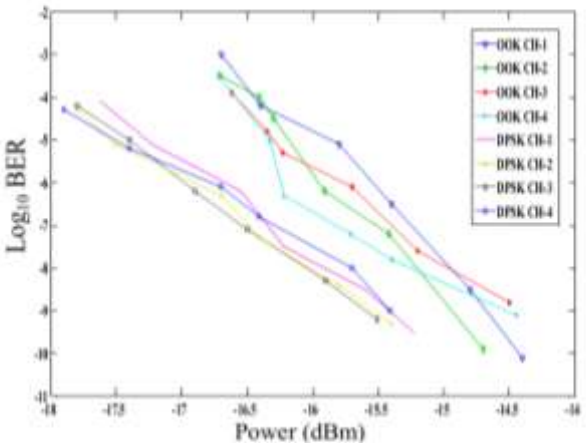

Fig. 2.Receiver power vs. BER for RZ-OOK and RZ-DPSK channels

23.5 ps. Pulse width of control signal is set to 23.5 ps as well, power per each control signal is set to 9dB higher than data signal, and the state of polarization is set to be orthogonal to data signal. Symmetrical Mach-Zehnder (SMZ) interferometer consists of two 50/50 couplers, two multiplexers, and two SOAs. Signal data are injected to SMZ through the upper input[9]. Two outputs of SMZ correspond- to “switching” and “reflective” ports. Output signals from both ports then go through the separate control pulses from data. Inputs to the receiver blocks will have only data signals. We vary the EDFA_1 power at transmitter side and measured the power at receiver side.

We observe that as we increase the input power we get better BER. Figure 2 shows the eye diagrams for both the formats.

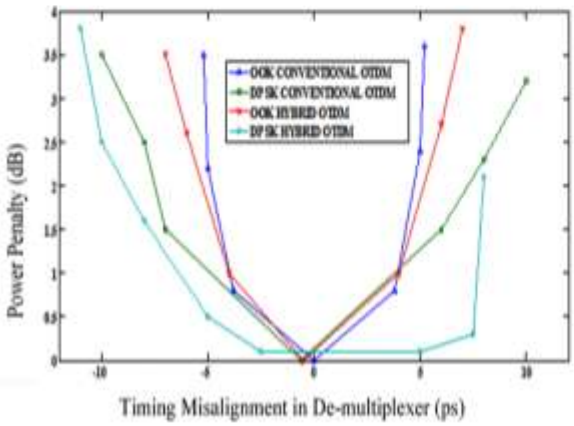

Fig. 3.The power penalty of respective de-multiplexed signals under the condition of timing misalignment

We could see the greatly enhanced tolerance to the adjacent crosstalk by employing hybrid OTDM signals. The

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measurement of power vs. BER has been taken from the simulation by varying the power of EDFA_1. The power of MLLD laser set -5dBm and EDFA_1 initial power set -10dBm. A power meter is connected before p-i-n-Photodiode. The plot between receive power and BER shown in Figure 2. Figure 3 depicts the measurements of the de-multiplexing performance under the condition of timing misalignment. The 1-dB tolerance of timing misalignment was around ±2.5 ps and ±3 ps, for conventional RZ-ASK OTDM and RZ-DPSK OTDM, respectively[3]. In our scheme, RZ- ASK channel is improved by 180 %, around ±7 ps almost three times for 1 dB tolerance. The RZ- DPSK channel has tolerance to enhancement of 70 % , to±5 ps. In case of de-multiplexing timing misalignment, if RZ- OOK is the targeted de-multiplexed channel then the switching window gated adjacent DSPK bits always added equalamount of power at detection for each ASK bit (either "0" or "1").

However, if consider DPSK as target de-multiplexed channel and gated adjacent ASK bits had different amount of power depending on the data bit patterns of the signal, that causes the power fluctuation after the de-multiplexing in the target channel. In above explanation we understand that why the RZ-ASK channels performed better than the RZ-DPSK channels in case of timing misalignment in de-multiplexing. From above simulated results, a timing misalignment for conventional 80 Gbps OTDM signal has tolerance of 1 dB was about 2.5 ps, i.e. 10% of the 80-Gb/s bit period [3]. It can further improve around 20% to 30% of the bit period by using our proposed hybrid OTDM.

III. CONCLUSION

The proposed hybrid OTDM can be used in optical transmission to increase the capacity of system. We use the RZ signal format which passes the advantage in operating with high input power, small inter-symbol interference and high receiver sensitivity. The simulated result shows that the tolerances to de-multiplexing timing misalignments were improved for both signal formats with an average BER 8.7651×10^{-10} for RZ-ASK and 4.8642×10^{-10} for RZ-DPSK (at received power -17dBm) have been achieved. We can increase the system capacity by eight times the channel capacity with better BER and less power penalty by using proposed OTDM system.

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