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An all-optical CSNRZ, DBNRZ& MDBNRZ to NRZ Format Conversion Strategy Based on a Single Mach-Zehnder Delayed Interferometer (MZ-DI)

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Abstract:

We proposed and demonstrated an all-optical format conversion strategy which has the capability to convert following modulation formats: carrier suppressed non-return to-zero (CSNRZ) to non-return to zero (NRZ), Duobinary non-return to zero (DBNRZ) to NRZ, Modified Duobinary non-return to zero MDBNRZ to NRZ, by exploiting cross-phase modulation (XPM) in a mach-Zehnder delayed interferometer (MZ-DI). It has been shown that proposed scheme exhibits fine performance upto 20 Gbps line rates. Further, in order to formulate optimum delay in MZ-DI structure, investigations have been carried out by varying delay of MZI-DI from 1 to 20 ps, and variations in Quality factor and Eye-opening factor (%) have been noticed at transmission port (T-port) of MZI-DI. Further, a comparison has been made in order to identify the most suitable input modulation format for the proposed format converter among CSNRZ, DBNRZ & MDBNRZ that yields best performance in terms of Q-factor, ER and EO (%) at the T-Port.It has been from observed from performance analysisthat CSNRZ is more suitable input format as compared to DBNRZ, MDBNRZ while converting to NRZ format all-optically utilizing the proposed MZ-DI scheme.

Keywords — **Non-linear optics, carrier suppressed non-return to-zero (CSNRZ), Duobinary non-return to zero (DBNRZ), Modified Duobinary non-return to zero (MDBNRZ), mach-Zehnder delayed interferometer (MZ-DI), cross-phase modulation (XPM), Format Conversion.**

I. INTRODUCTION

With demand for high bit rate and long-distance transmission is constantly increasing, and recently it has been observed that the main focus of several research studies is to improve the network flexibility and to increase the network size. So, for this all-optical format conversion is crucial interfacing scheme between optical time division network (OTDM) and wavelength division multiplexing network (WDM) [1-7]. All-optical received more interest owing to its ultra high response and by eliminating and optical to electrical and electrical to optical (O-E-O) conversion [4, 8-17].The on-off–keying signal is mainly employing optical communication system which transfers information either in return to zero (RZ) and non-return to zero(NRZ)formats[6, 8].The return to zero(RZ) format is widely used in optical time division multiplexing networks because it is more tolerant to polarization mode dispersion(PMD) [6, 18].While the NRZ is preferred in WDM networks owing to its higher spectral efficiency, simplicity and it more tolerant to timing jitter. Although, for transmission of RZ format needs two times more bandwidth than NRZ transmission [3, 6, and 7]. The on-off keying signal mainly used over a small distance means between backbone network and metropolitan area network [1, 9]. In order to fulfill the demand for high bit rate and long-distance transmission we need advanced type of modulation format the reason behind this fact is that different networks used different modulation format according to their network's coverage [4]. Advanced modulation format mostly adapted between wide area networks and transoceanic undersea cable networks [8]. Gateway node is used in optical communication its key function is, it interconnect different segments of network with each other by modulation format conversion because every network use different modulation format. So, at the gateway node modulation format conversion is required to make suitable of incoming signal from one segment for another segment of network [8, 9]. Different modulation format conversion schemes have been demonstrated, previously.

S.H. Lee et al. (2005) proposed and demonstrated the NRZ to RZ and RZ to NRZ format conversion based on cross phase modulation(XPM) by using dispersion shifted fiber (DSF [19].

K. Mishina et al. (2007) proposed and experimentally demonstrated the NRZ-OOK to RZ-QPSK format conversion based on parallel SOA-MZI OOK/BPSK converters. The proposed modulation format conversion is based on XPM and orthogonal interference [8].

K. Mishina et al. (2007) numerically simulated and experimentally demonstrated the format conversion from NRZ-OOK to RZ-BPSK and NRZ-OOK to RZ-QPSK at 10.7 Gb/s and10.7 Gsymbol/s respectively, which was based on non-linearity in optical fiber. [18].

J. Wang et al. (2009) proposed and simulated format conversion from non return to zero(NRZ) to return to zero(RZ) using sum-frequency generation (SFG) in a periodically poled lithium niobate loop mirror (PPLN-LM) at 40 Gb/s[20].

P. Honzetko et al. (2010) experimentally and theoretically demonstrated RZ to NRZ modulation format conversion at 10 Gb/s and 20 Gb/s based on optical non-linear loop mirror (NOLM).In this study, a 1200m long non-zero dispersion shifted fiber was used as the non-linear medium [1].

Y. Yu et al. (2011) proposed and demonstrated for 6 channel parallel format conversion from NRZ-DPSK to RZ-DPSK using a single SOA at 40 Gb/s. Cross phase modulation effect in SOA has been used for realization purposes [2].

B. Zou et al. (2011) proposed and experimentally demonstrated NRZ to RZ format conversion for eight channels simultaneously using single SOA and subsequent delay interferometer at 40 Gb/s based on cross phase modulation introduce in single SOA. [3].

S. Singh et al. (2011) described and investigated the format conversion between RZ and NRZ using Mach-Zehnder interferometer and a single SOA in MZI, at 120 Gb/s and 40 Gb/s respectively [7].

G. Huang et al. (2012)proposed and numerically demonstrated the OOK to 16 QAM modulation format conversion using non-linear optical loop mirror (NOLM) at 10 Gbps based on the cross-phase modulation and parametric amplification in optical fibers [4].

B. Zou et al. (2012) studied and demonstrated the NRZ-QPSK to RZ-QPSK format conversion due to constructive interference in half bit delay interferometer at 40 Gb/s [10].

B. Zou et al. (2013) proposed and experimentally demonstrated the NRZ-QPSK to RZ-QPSK format conversion by employing single SOA and half bit delay interferometer based on cross phase modulation [5].

M.H.A. Wahid et al.(2014) proposed and experimentally investigated for 4 channel NRZ to CSRZ and RZ to CSRZ format conversion by employing SOA-NOLM at 10 Gb/s [11].

H. Cao et al. (2014) proposed and demonstrated the conversion of data format from RZ-OOK to NRZ-OOK using a single fiber Bragg Grating at 20 Gb/s. [21].

M. Y. Ya et al. (2015) proposed and experimentally demonstrated format conversion from NRZ-DPSK to RZ-DPSK by employing terahertz optical asymmetric Demultiplexer (TOAD) at 10 Gb/s. [6].

The need for these conversions is to acquiring higher bandwidth for optical communication. In backbone networks, all networks utilize different format conversion schemes according to distance and size. It has been observed from the study of the literature that no one has ever attempted to convert advanced modulation formats such as CSNRZ, DBNRZ and MDBNRZ to NRZ format.So, in this paper for the first time to our best knowledge, we proposed and demonstrated format conversions of CSRZ to NRZ, DBNRZ to NRZ and MDBNRZ to NRZ using MZ-DI. We analyzed the performance CSNRZ to NRZ, DBNRZ to NRZ and MDBNRZ to NRZ formats conversions by employing MZ-DI at 20 Gb/s based on cross phase modulation. For performance evaluation purposes, quality factor, eye opening factor (%), extinction ratio at 20 Gb/s has been measured of format converted signal obtained at transmission port (T-port) of MZI-DI. These conversions are based on cross phase modulation (XPM) process taking place in MZ-DI. It has been observed that proposed strategy can CSNRZ to NRZ format conversion more efficiently as compared to other two format conversions based on extinction ratios and quality factor obtained at T-port of MZ-DI. The article is organized as follows: In I section brief introduction is given about format conversions. In section II, operation principle of MZ-DI has been described. Then, in section III we explained the simulation setup for all the three format conversions schemes. In section IV, we discuss the results and discussions related to all threeall-optical format conversion schemes. Conclusions are addressed in section V.

II. OPERATION PRINCIPLE

The basic principle of Mach- Zehnder delay interferometer is when a signal is passed through two arms of MZ-DI with distinct length from same source by input coupler. We will receive phase shifed signal at the output due to constructive and destructive interference. Basically MZ-DI is a device which is employing to determine shift in phase of signal at the output when a signal is inserted in two different length of arms from the same source. As shown in Fig.1when input NRZ signal is passed through delayed and undelayed arms using input coupler. Here upper arm is delayed and lower arm is undelayed. At the output of coupler we obtained RZ output signal due to the combination of these two signals i.e. delayed and undelayed at the output coupler. We can determine that consecutive ones in bit sequence changes between two levels and in resulting RZ signal is obtained [7]. A very similar strategy has been utilized in conversion of CSNRZ, DBNRZ & MDBNRZ to NRZ formats in the proposed approach.

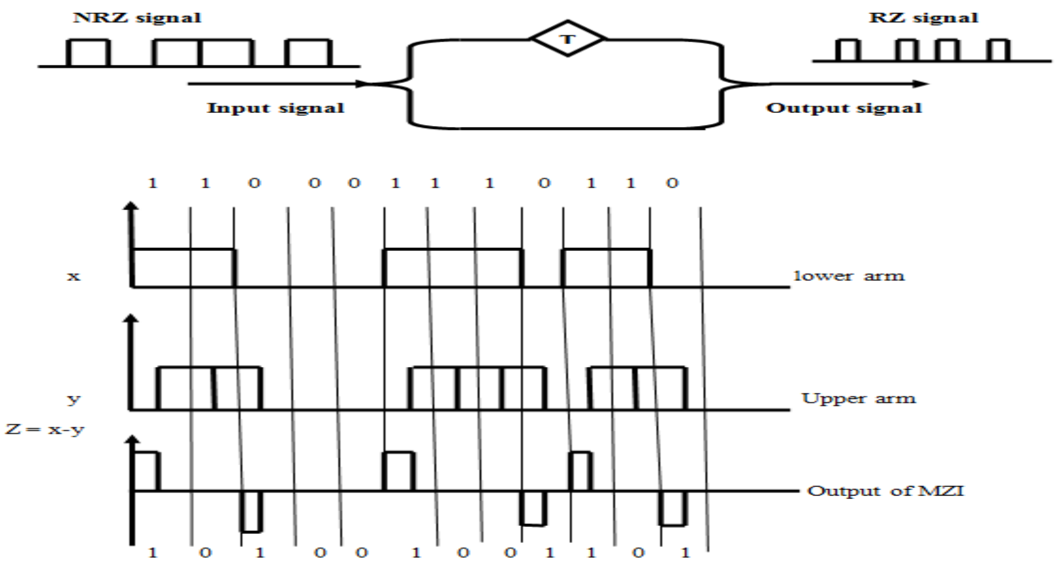

Fig.1 Format conversion of NRZ to RZ using MZ-DI [7]

III. SIMULATION SETUP

A. Simulation setup for CSNRZ to NRZ format conversion

The simulation setup deployed for demonstration of CSNRZ to NRZ format all-optically is illustrated in Fig.2.

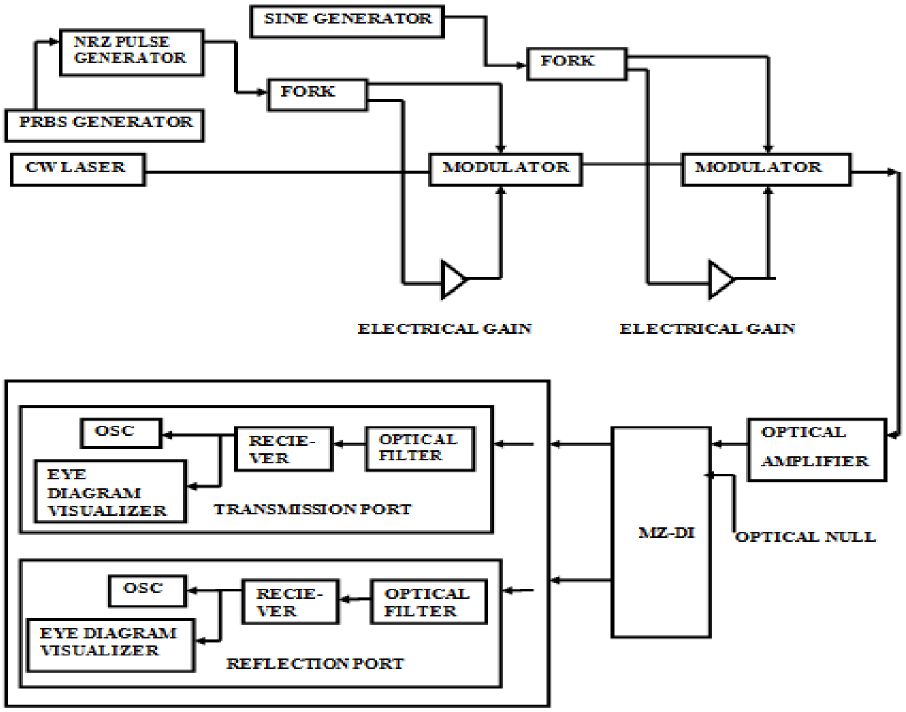

Fig.2 Schematic diagram for CSNRZ TO NRZ format conversion

A Pseudo random bit sequence (PRBS) generator generates the random data in binary form as in '0' or '1' bit stream. NRZ generator generates the NRZ signal of bit stream pulses. A continuous wave (CW) laser generates CW light at wavelength of 1558.2 nm which has -3dBm power. Two $LiNbO_3$ Mach-Zehnder modulators which are cascaded with each other and modulate the generated NRZ signal before applying to the MZ-DI. After first modulator, NRZ signal is

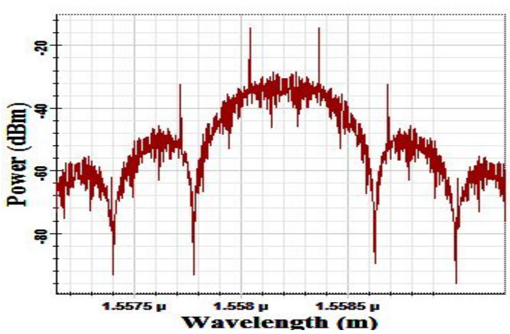

Fig.3 Frequency spectrum of CSNRZ signal

then passed through the second modulator which is driven by sine generator with a frequency equal to of the bit rate and zero phase shifts will be introduced between two adjacent bits. The central peak at the carrier frequency will suppress frequency spectrum is shown in Fig. 3 of CSRZ signal.

At the output port of modulator CSNRZ signal is fed into the delay interferometer through optical amplifier which is in between modulator and interferometer. Gain and noise figure of optical amplifier is 23 dB and 8 dB respectively. The time delays of Mach-Zehnder delayed interferometer (MZ-DI) can be varied from 1 to 20 ps by adjusting length of one arm of MZ-DI. At the output port of interferometer converted format obtained i.e NRZ. Then NRZ signal in optical form passes into optical Band pass Bessel filter before applying to the PIN photo detector. Frequency of optical Bessel filter is 1558.2 nm, insertion loss is 3 dB and bandwidth is 1.1 nm. Then the filtered output signal is converted into electrical signal using PIN photo detector which has 10 nA dark current, NRZ in electrical form is fed to the low pass Bessel filter which has 30 GHZ cut off frequency. At the output port of low pass filter we obtained desired converted NRZ signal in electrical form. Further, an eye diagram analyzer has been deployed at receiver side in order to evaluate quality of obtained NRZ format converted signal.

B. Simulation setup for DBNRZ to NRZ format conversion

The simulation setup deployed for demonstration of DBNRZ to NRZ format all-optically is illustrated in Fig.4 as follows:

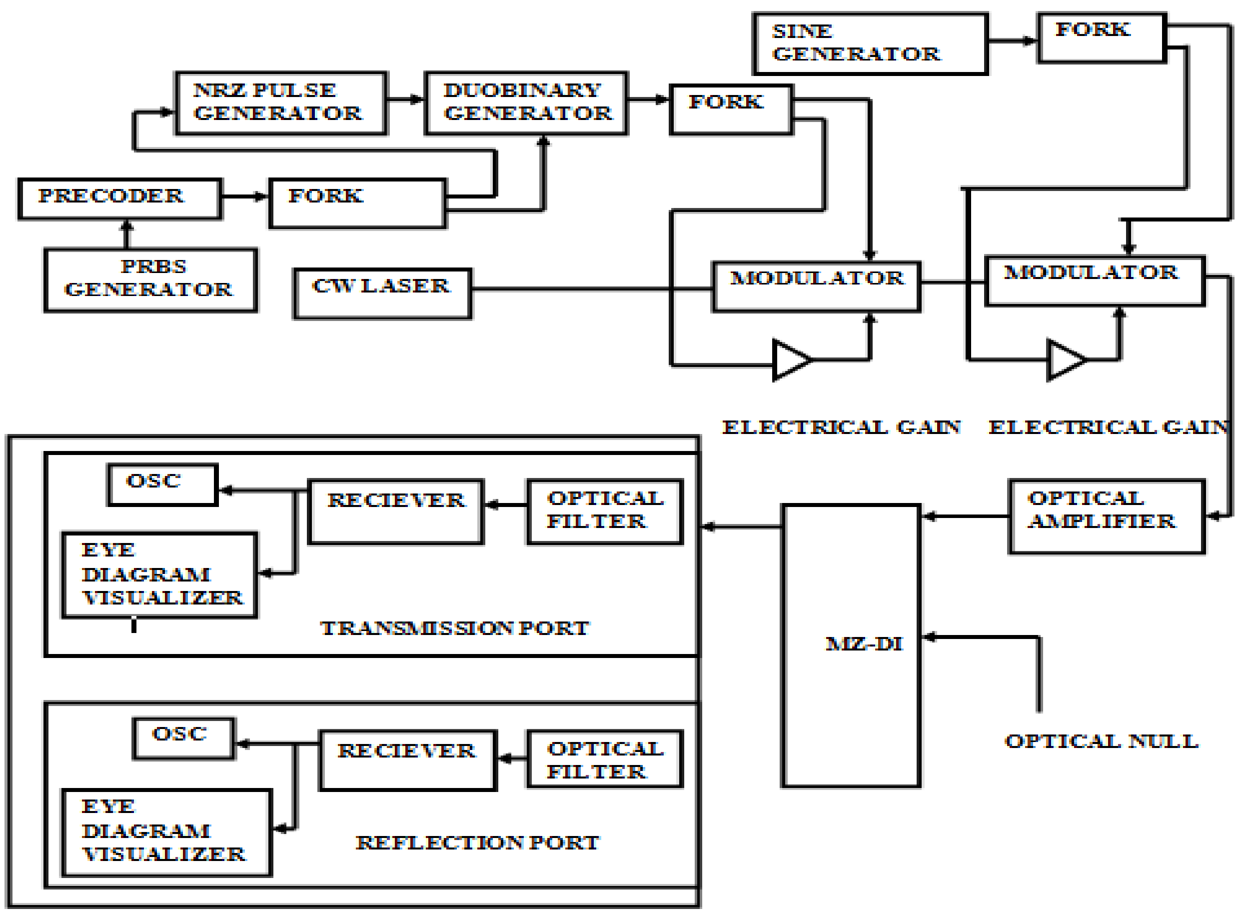

Fig.4 Schematic diagram for DBNRZ TO NRZ format conversion

Fig.4 presents the simulation setup for DUOBINARY NRZ to NRZ format conversion. Pseudo random bit sequence (PRBS) generator generates the bit stream of transmitted data. Duobinary signal is produced by employing precoder, NRZ generator and duobinary generator. Precoder is the combination of exclusive-OR gate and delayed feedback path. We have deployed two Lithium niobate Mach –Zehnder modulators (MZM) which are cascaded with each other. First MZM modulator is driven by duobinary generator and second modulator is driven by sinusoidal electrical signal with frequency equal to bit rate and phase -90 which is generated by sine generator. The operating wavelength of CW laser is 15588.2 nm and power is -3 dBm. At the output of modulator duobinary signal is applied to the MZ-DI but optical amplifier is used in between modulator and interferometer. Gain of optical amplifier is 23 dB and noise Fig. is 8 dBm. The time delay between two arms of MZ-DI is tunable in following range: 1 to 20 ps. At the Transmission port (T-Port) of MZ-DI, NRZ signal in optical form then it passed into Bessel optical filter and then filtered optical signal fed to the PINphotodetector which has 30 GHZ cut off frequency and insertion loss is 0 dB. At the output port of photo detector, we get NRZ signal in electrical form. Then the electrical signal passes through low pass filter for desired NRZ signal in electrical form. Low pass filter is connected with eye diagram visualize and oscilloscope visualize for visualizing the eye diagram and NRZ spectrum respectively. In Optical spectrum of DBNRZ carrier has been suppressed as presents in Fig. 5 as follows:

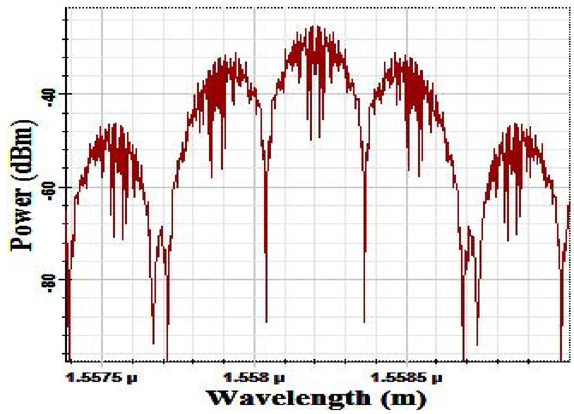

Fig.5 Frequency spectrum of DBNRZ signal

C. Simulation setup for MDBNRZ to NRZ format conversion

The simulation setup deployed for demonstration of DBNRZ to NRZ format all-optically illustrated in Fig.6 as follows:

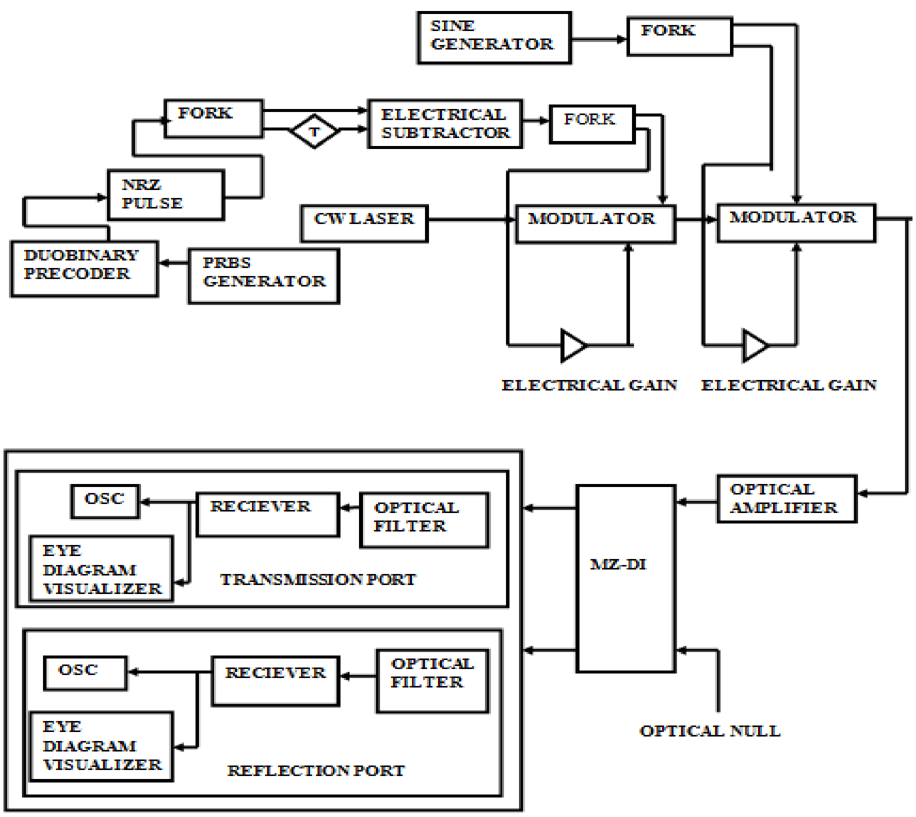

Fig.6 Schematic diagram for MDBNRZ TO NRZ Format conversion

For MDBNRZ to NRZ format conversion, simulation setup as shown in Fig.6. Modified duobinary format is also known as carrier suppressed duobinary format. At the input PRBS (pseudo random bit sequence) generator, generates the original data which we want to be send or transmitted in binary form means ' 0' and '1' form. NRZ Duobinary signal is created by employing duobinary precoder, NRZ pulse Generator, electrical delay and electrical subtractor before generating modified duobinary NRZ signal. The first MZM modulator is driven by electrical delay and subtractor circuit and then this modulator cascaded with next modulator that is driven by electrical sinusoidal signal which is generated by sine generator on bit rate and phase is -90. A CW Laser generates CW light at 1558.2 nm wavelength and power has -3dBm. Modulators, modulate the modified duobinary signal before applying to the Mach-Zehnder interferometer. Thus, generated MDBRZ signal before being fed to MZI is further amplified with the help of an optical amplifier signal possessing following characteristics: 8dB noise Fig. and Gain is 23 dB. At the T-Port of interferometer we obtain converted NRZ signal in optical form. The output generated form T-port of MZ-DI interferometer is then connected with PIN photo detector through Bessel optical filter. Then NRZ electrical signal fed to the Bessel low pass filter. At output port of this filter we obtained desired converted NRZ signal in electrical form. Time delay of interferometer is fixed at 1 to 20 ps. In modified duobinary signal for bit '1' phase is alternated at 0 and 180 whereas in duobinary signal, is employing before modified duobinary signal phase of bit '1' altered only after bit '0'. Frequency spectrum is shown in Fig. 7 as follows:

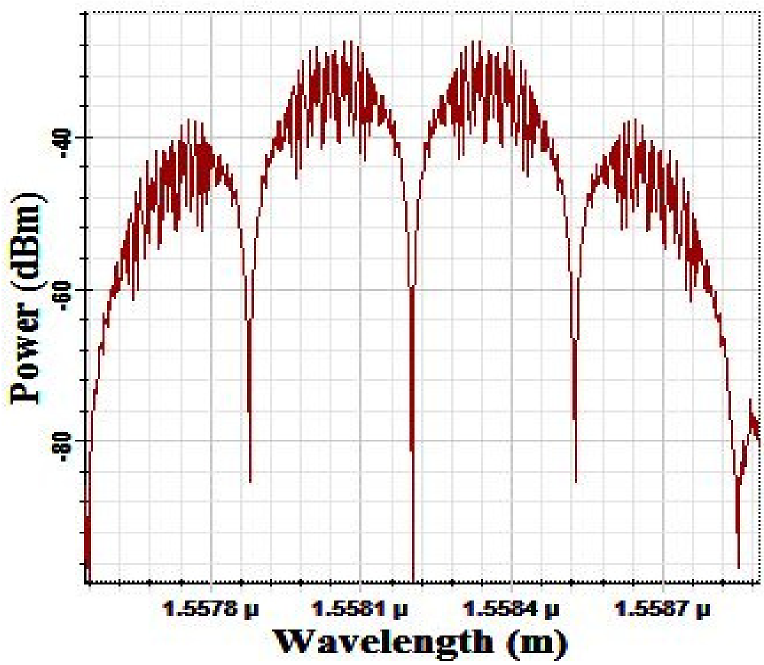

Fig 7 Frequency spectrum of MDBNRZ signal

IV. RESULTS AND DISCUSSIONS

Fig.8 (a-c) presents time domain spectrum for input and output signal at 10 Gb/s for three different format conversions i.e. a) CSNRZ to NRZ b) DBNRZ to NRZ and c) MDBNRZ to NRZ. It can be observed from Fig. 8 (a-c) that the proposed MZ-DI based strategy can convert all three input modulation formats such as CSNRZ, DBNRZ and MDBNRZ very effectively into NRZ format. Further, Fig.9 describes the eye diagrams of CSNRZ, DBNRZ and MDBNRZ at the of MZI at 10 and 20-bit rates which indicate the successful operation of MZI based proposed format conversion scheme. Eye opening diagram have been measured by considering 1024 sequence length which is generated by PRBS generator, each bit having 64 samples per bit.

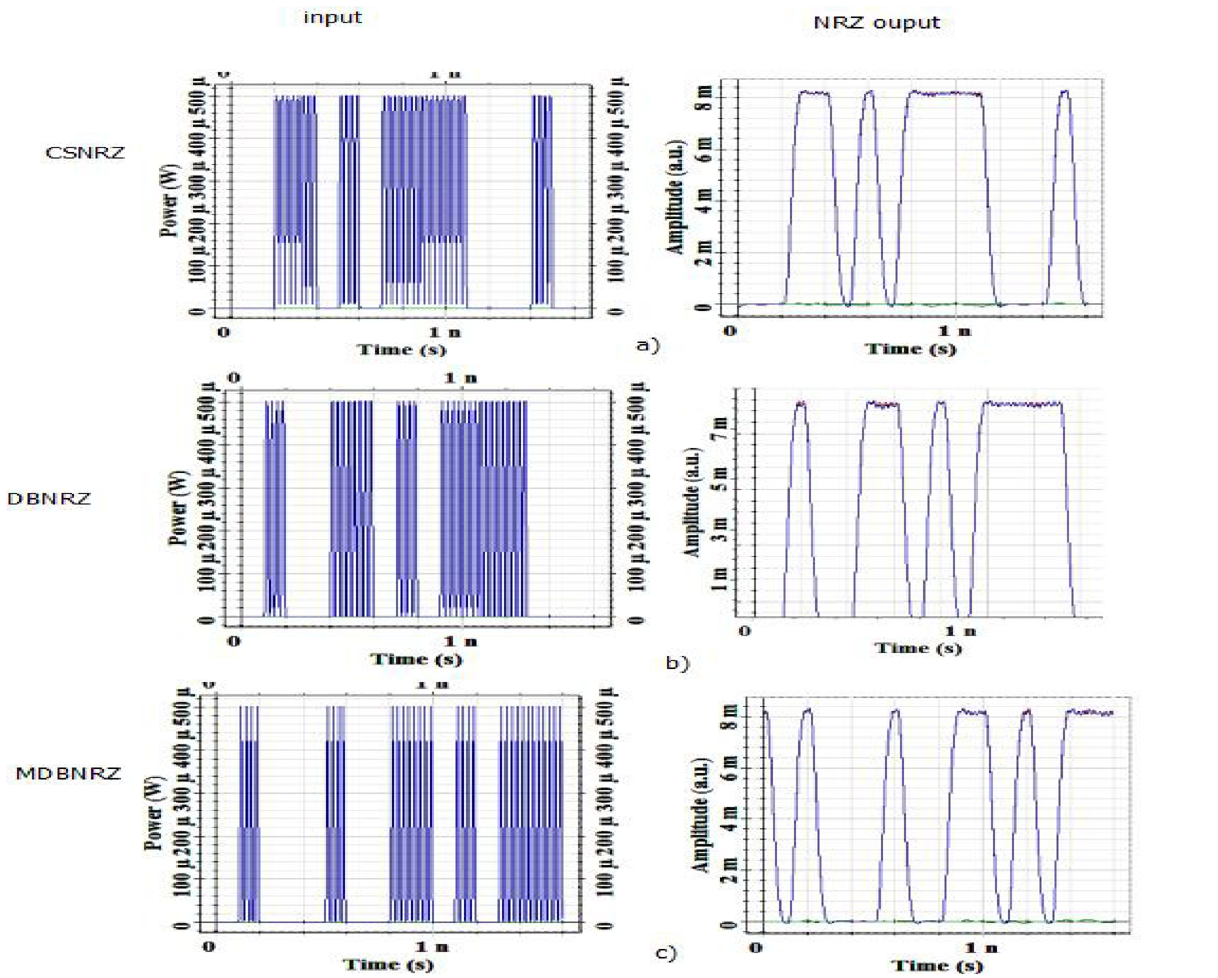

Fig.8 temporal traces of input signal and output signals a) CSNRZ input signal and NRZ output signal b) DBNRZ input signal and NRZ output signal c) MDBNRZ input signal and NRZ output signal

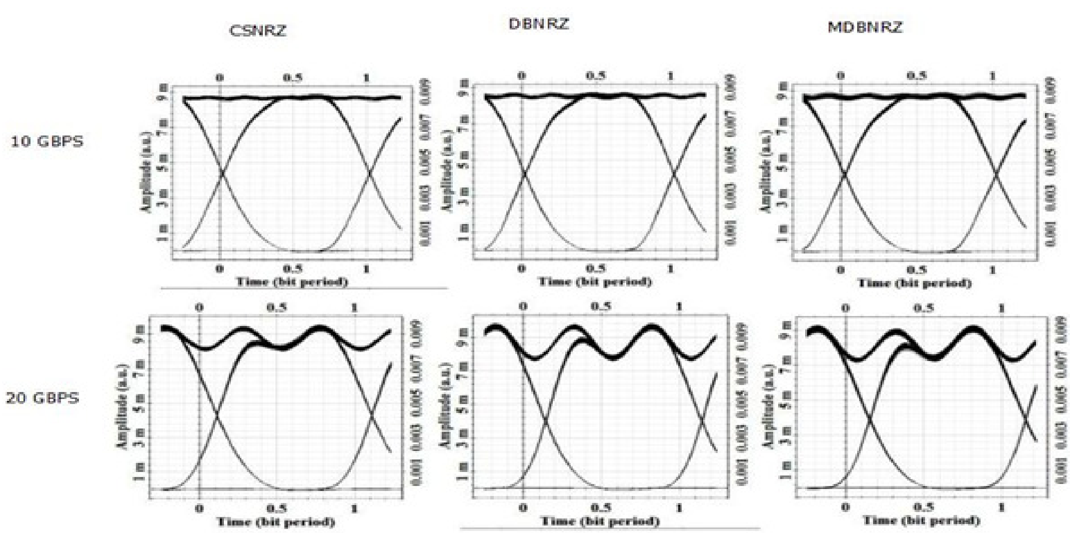

Fig 9 Eye opening diagrams of CSNRZ, DBNRZ, MDBNRZ at transmission port of MZI at different bit rates.

Further, in this work, the performance analysis of three types of format conversions which are CSNRZ to NRZ, DBNRZ to NRZ and MDBNRZ to NRZ has been presented. Firstly, we compared the eye-opening factor (%) of converted signal at transmission port (T-port) of MZ-DI at different powers of input signal being fed to the proposed MZ-DI structure for CSNRZ to NRZ format conversion as shown in Fig.10.

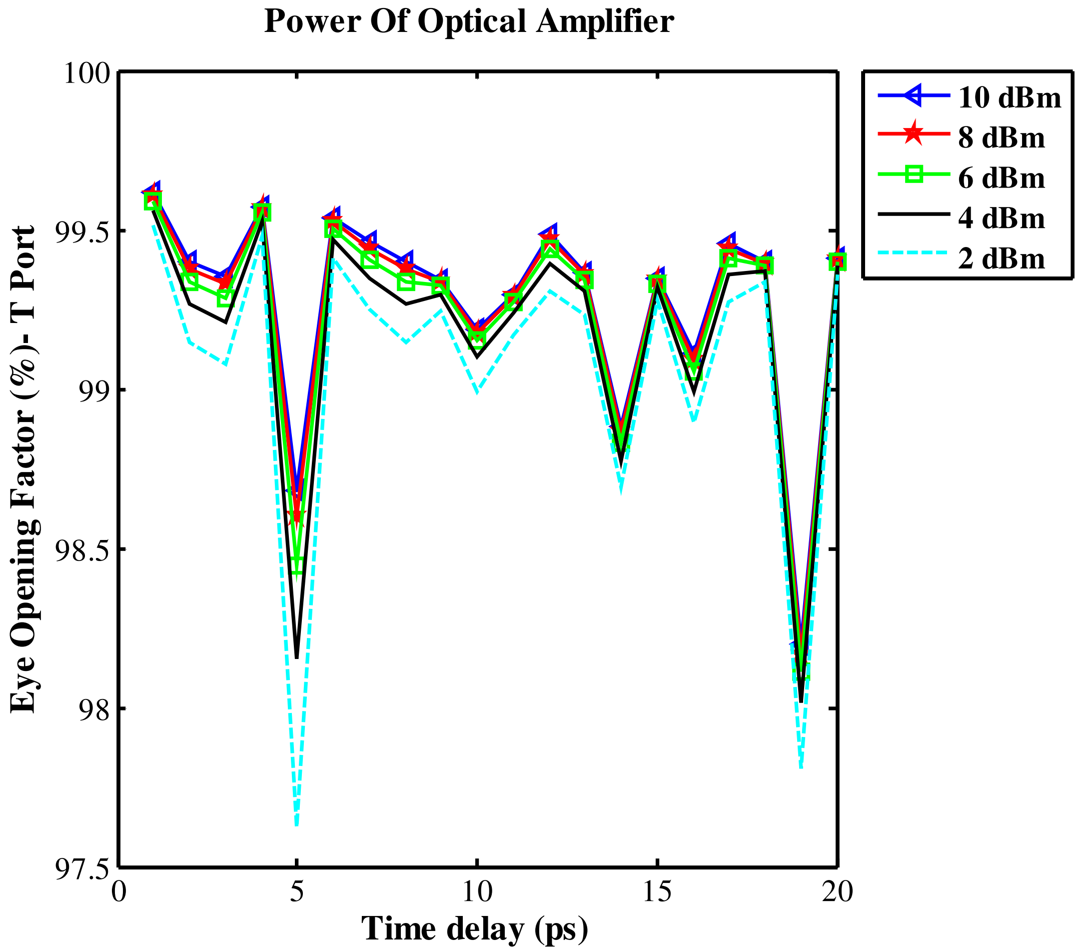

Fig.10 Comparison of eye opening factor (%) versus time delay for different powers of input signal being fed to proposed MZ-DI structure for CSNRZ to RZ format conversion.

Here, we demonstrated that at 10 dBm input power,EO (%) recorded is highest. Beyond this value eye opening factor remains constant. There will be no any change in EO (%). So, we selected 10 dBm input power as optimum input power. In the same way we investigated the best value of input power for DBNRZ to NRZ and MDBNRZ to NRZ format conversion. It has been also observed that for these two cases also 10 dBm input power is best.Fig.11, 12 and 13 shows the comparison of CSNRZ, DBNRZ and MDBNRZ to NRZ format conversions in terms of eye opening factor (%) at different data rate. From these figures It can be analyzed that at 20 Gb/s all the converters exhibit good performance. Beyond this bit rate (20 Gbps) the performance of proposed format converter starts to degrade for all three conversions. We observed at 10 Gb/s, EO (%) is maximum for all the converters but at 40 Gb/s eye opening factor will decrease gradually with increase in time delay. Further, in order to evaluate the impact of time delay (ps) on proposed format converter, further investigations have been carried out and results obtained at 20 Gbps are presented in Fig. 14 as follows:

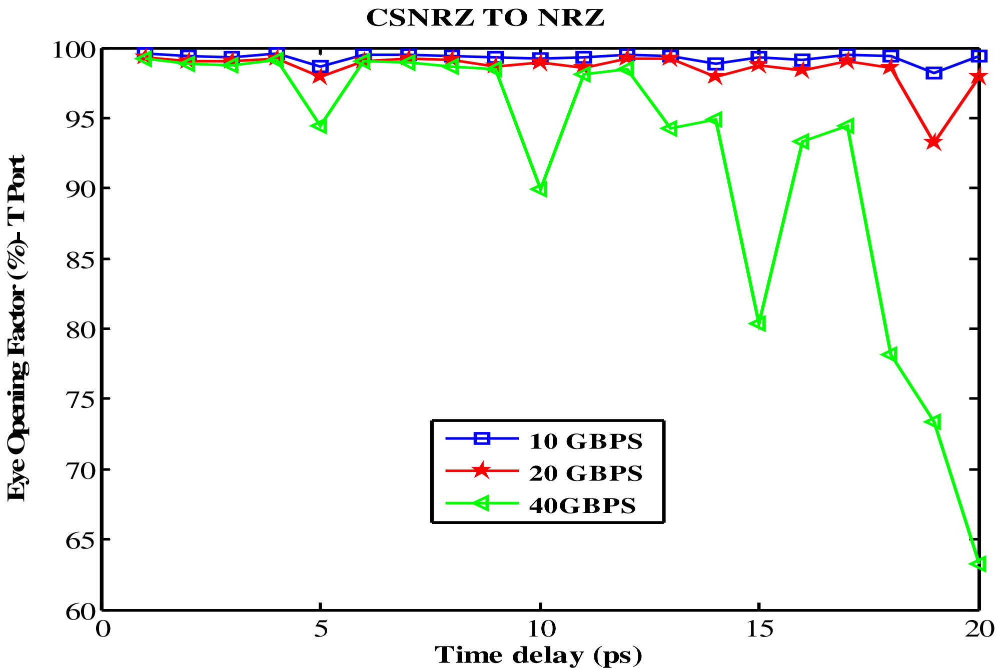

Fig.11 Comparison of eye opening factor (%) at T-port versus time delay (ps) at different data rate for CSNRZ to NRZ conversion

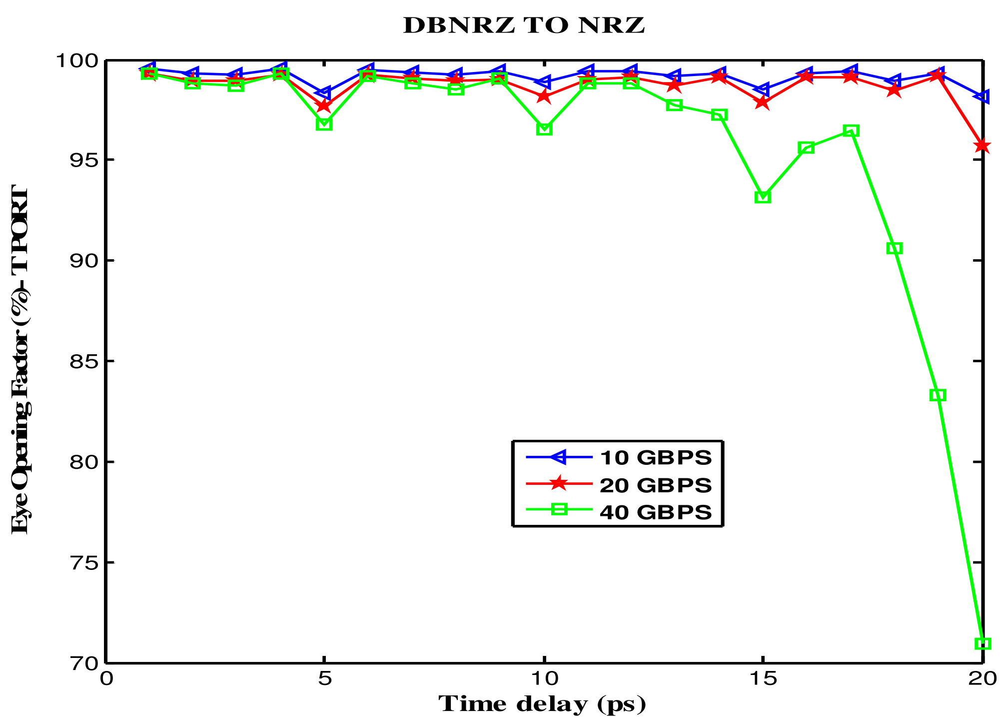

Fig.12 Comparison of eye opening factor (%) at T-port versus time delay (ps) at different data rate for DBNRZ to NRZ conversion

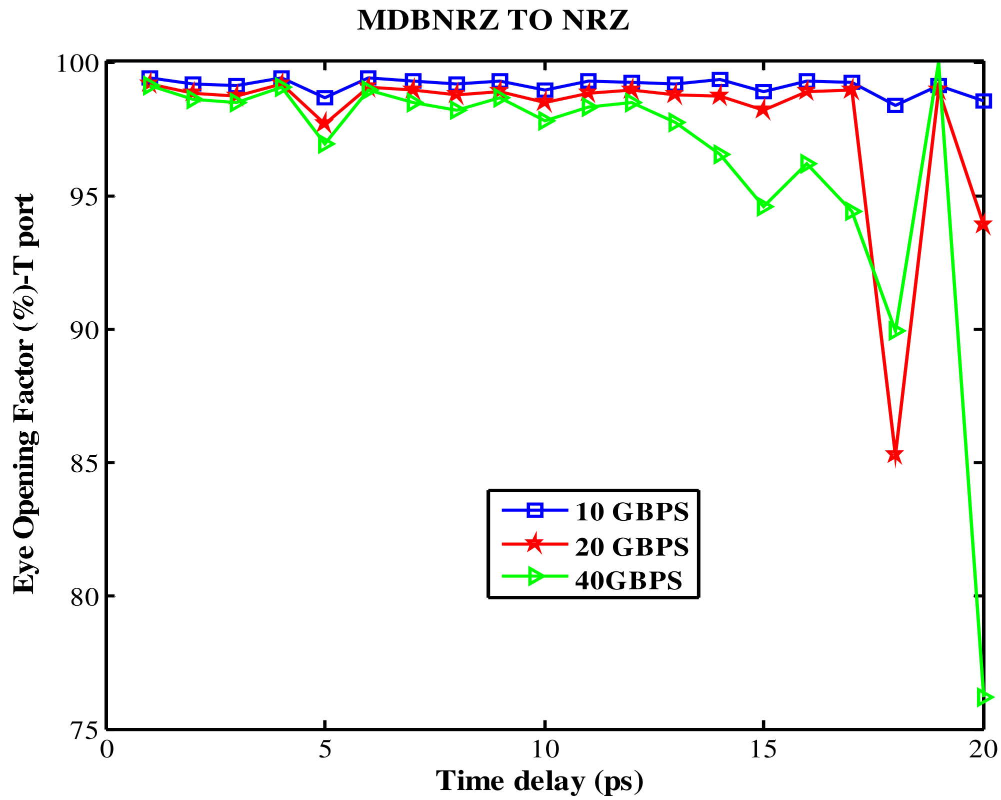

Fig.13 Comparison of eye opening factor (%) at T-port versus time delay (ps) at different data rate for MDBNRZ to NRZ conversion

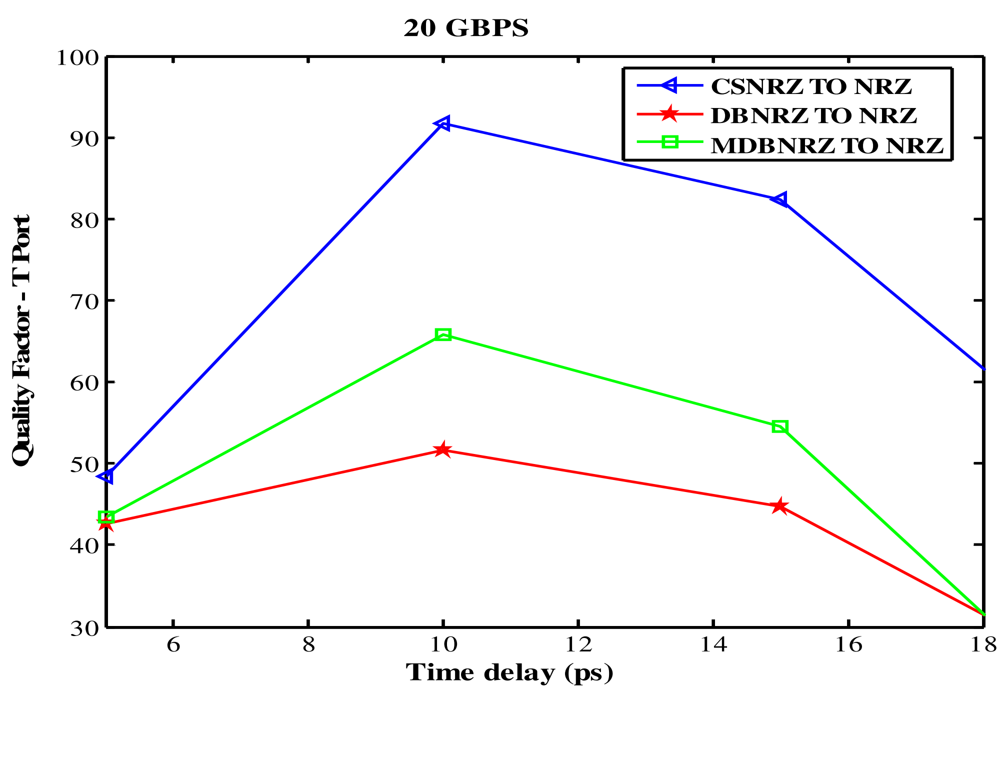

Fig.14 Comparison of quality factor versus time delay (ps) for CSNRZ, DBNRZ and MDBNRZ to NRZ format conversion at 20 Gb/s

It can be observed from Fig. 14, that value of delay = 10 ps suits all the three format conversions utilizing the proposed strategy. Increasing the delay beyond 10 ps value results in degradation in performance of proposed all-optical format converter.

Further, Table 1 shows the comparison of CSRZ to NRZ, DBNRZ to NRZ, MDBNRZ to NRZ format conversion at 20 GB/s based on extinction ratio at the transmission port of MZ-DI at 1 to 20 ps time delay of Mach- Zehnder interferometer.

TABLE 1 Comparison of Extinction ratio for CSRZ to NRZ, DBNRZ to NRZ and MDBNRZ to NRZ format conversion at 20 GB/s at 1 to 20 ps time delay.

Time delay (ps)	ER (CSNRZ TO NRZ)	ER (DBNRZ TO NRZ)	ER (MDBNRZ TO NRZ)
1	18.7231	20.3844	20.0212
2	19.5371	21.3001	22.978
3	19.8098	20.677	20.5262
4	18.4801	20.0764	19.531
5	22.9213	22.5962	23.8533
6	18.4321	21.7201	20.3917
7	20.4203	20.3255	22.4233
8	21.2714	19.4008	21.9401
9	20.5398	23.7887	19.1323
10	23.9472	23.2706	22.7958
11	20.3548	23.4562	19.2896
12	20.2106	19.7964	20.652
13	22.6598	20.2703	21.9556
14	42.713	26.0972	22.8777
15	24.2404	29.9371	27.9076
16	23.006	24.3829	19.8952
17	19.061	21.1059	20.7132
18	22.4504	21.7488	25.2545
19	18.1604	24.945	23.2802
20	22.6931	20.5614	19.743

It can be observed from Table 1 that CSNRZ to NRZ format conversion has 42.713 dB maximum extinction ratios at 14 ps time delay. Whereas maximum extinction ratio of MDBNRZ to NRZ format conversion is 27.9076 dB at 15 ps time delay and for DBNRZ to NRZ format conversion extinction ratio 29.9371 dB at 15 ps time delay. These values determine that extinction ratio maximum in case of CSNRZ to NRZ format conversion. So, we can say that performance CSNRZ to NRZ format conversion is best in comparable with other two format conversions based on extinction ratio.

V. CONCLUSIONS

We proposed and simulated an all optical format conversion scheme capable of converting following formats: CSNRZ to NRZ, DBNRZ to NRZ and MDBNRZ to NRZ based on XPM harnessing in a single MZ-DI structure. It has been show that proposed schemes exhibit good performance upto 20 Gbps line rates. We investigated the EO (%), ER and Quality factor with respect to time delay within specified range from1 ps to 20 ps at the T-port of MZ-DI.It has been observed that with increase in time delay beyond 10 ps, quality of the signal starts decreasing. Further, we have observed that fine performance has been exhibited by proposed strategy in terms of quality factor and extinction ratio for CSNRZ, DBNRZ, MDBNRZ format conversions while demonstration. It has been observed that CSNRZ format conversion is more suitable than other two conversions (DBNRZ and MDBNRZ) in terms of quality factor and extinction ratio while converting to NRZ format all-optically utilizing the proposed MZ-DI scheme. We obtained maximum extinction ratio while converting CSNRZ to NRZ format which was 42.713 dB at 14 ps time delay.

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