Simulative Analysis of Robustness of Various Modulation Formats for Optical CDMA using 2D Codes for Different Encoders at 10Gbps

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This paper reports the simulative analysis of NRZ, RZ, carrier-suppressed RZ (CSRZ) and duo-binary (DB) modulation formats for optical code division multiple access (OCDMA) system for two different types of encoders at 10 Gbps. The investigations reveal that highest Q^2(dB) of the order of 16.5;14.5;6.2 and 3.8 has been obtained when we use combination of optical filters and time delay components as optical encoders in OCDMA system for CSRZ, DB, RZ and NRZ formats respectively. It is also observed that for fiber Bragg grating (FBG's) as optical encoders, Q^2 (dB) of the order of 17.7;11.8;7 and 4 is achieved in case of DB, CSRZ, RZ and NRZ formats respectively. CSRZ and duo-binary formats have shown the robustness over other formats for OCDMA system using filter, time delay components and fiber Bragg gratings (FBGs) as optical encoders respectively. The maximum eye opening in case of these formats further proved their efficiency.

Keywords: Optical CDMA; Modulation formats; Fiber Bragg gratings (FBG's); Optical filters; Time delay components

1 Introduction

During the past years due to the availability of large bandwidth in optical domain, spread spectrum techniques are used for multiple-access systems to make efficient use of this bandwidth. Among all the multiple access techniques like time-division multiplexing (TDM), frequency-division multiplexing (FDM) and wavelength-division multiplexing (WDM), optical code- division multiple- access (OCDMA) combines the huge bandwidth feature of optical domain with flexibility of CDMA to achieve high data rate systems[1-7]. Due to its unique features of processing information in optical domain, easy access, flexible structure, soft capacity and above all information security, OCDMA has fetched the interest of various researchers. OCDMA is a technique that performs transmission, reception and multiple access in optical domain by imparting a unique pseudo random code to all the users to access the same transmission bandwidth[8-15]. Optical pulses are encoded at the transmitter side by using optical encoders with respect to certain coding arrangement and are assigned to a particular user accessing the system. Optical decoder at the receiver end decodes the code using match filter and inverse time delay components[16-24].

The use of OCDMA system over long transmission lengths is affected by chromatic dispersion as many users access the system simultaneously, polarization mode dispersion (PMD) at high bit rate and fiber impairments at high power level. However, these types of performance degradation factors can be minimized to a greater extent if the transmitted signal possesses some special characteristics. This leads to the choice of suitable optical modulation format for OCDMA system. The commonly used modulation formats are non return-to-zero (NRZ) and return-to-zero (RZ) formats. Due to narrow optical spectrum, NRZ format possess high spectral efficiency in linear range. But with increase in data rates, RZ modulation format shows robustness in comparison to NRZ especially for the distortions produced by non linear effects in optical fibers[25]. Still, the RZ signal format suffers the impairments caused by multiple access interference between the users.

To further enhance the performance of system, those impairments have to be minimized. Carrier suppressed return-to-zero (CSRZ) is used for high data rate systems as they possess very less spectral width and improve the spectral efficiency of the system[26]. Similarly, duo-binary (DB) format derived by combining standard amplitude shift keying (ASK)

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and phase shift keying (PSK) is also a promising format to combat with dispersion and fiber non linearity with a reduced spectral width[27]. Duo-binary modulation also provides the suppression of SBS effect due to suppression of carrier in it. In this format, various levels of signal are coded in to optical states by modulating both the intensity as well as phase of the signal[28-29]. Duo-binary technique is used in metro area networks too as it possess high tolerance to dispersion.

Up till now, mostly NRZ and RZ modulation formats have been investigated and suggested by various researchers for increasing the spectral efficiency of the OCDMA system using one dimensional code. In this manuscript, analysis of optical CDMA system is done for NRZ, RZ, CSRZ and duo binary modulation by using two types of optical encoders at 10 Gbps for two dimensional (2D) codes. Performance metrics like Q-factor, received optical power (ROP), optical signal to noise ratio (OSNR) and eye diagrams have been indicated. The rest of the paper is organized as follows. After a brief introduction of the basic OCDMA system with a various modulation formats used in the paper in section 1, section 2 substantiates the system configuration and its description, section 3 reports the results and finally section 4 concludes the paper.

2 System Configuration and Description

The OCDMA system is set up and simulated as shown in Fig. 1(a) by a commercial optical communication simulation tool, Optisystem^{TM} version 11. This system investigates and compares the performance of NRZ, RZ, CSRZ and duo-binary formats for optical CDMA system by using two different kind of optical encoders. These modulation formats are generated in the optical domain. The generation of duo-binary and CSRZ modulation format is shown in Fig. 1(b-c) respectively. The system is designed by using two dimensional (2D) optical orthogonal codes for different number of users. First type of optical encoder consists of a group of optical filter and time delay components to impart wavelength and delay to the code of a particular user respectively to form the wavelength/time code and to produce the encoded bit stream at the transmitter side as shown in Fig. 1(d) Out of n number of wavelengths produced by the modulator, optical filter is used to filter out any one spectral wavelength and then time delay component produce a pulse at spectral chip interval. The cut off frequency of filter is taken as

quarter of the bit rate to filter the targeted spectral wavelength. The multiplexer then combines the displaced pulses to output an encoded signal[6].

The second type of optical encoder make use of fiber Bragg gratings FBG's to implement same set of two dimensional optical orthogonal codes. The structure of the system is as shown in Fig. 1(e) below. It comprises of a *1xw* power splitter, where each arm is connected to a linear array of n fiber Bragg gratings, each separated by a constant length L_{sep}. In total there are *wxn* FBG's each having the same wavelength λ_r Ɛ [λ_{min}, λ_{max}]. The position of these FBGs represents the time slots of the various wavelengths[7]. Transmitter part of the system comprises of optical source and optical encoder basically. Eight continuous wave lasers, wavelength range from 1549.2 nm to 1554.8 nm with spacing of 0.8 nm are used to create a broadband light source. The PRBS generator is used to generate a sequence of bits according to the code. Then four types of pulse generators are used to produce the NRZ, RZ, CSRZ and duo-binary pulses to analyze the performance of the system separately. The modulator used is mach zehnder modulator that is operated by an electrical signal with corresponding data rate. The modulated signal is then transferred to encoder. The encoded signal is sent through the optical channel that consists of standard single mode fiber, amplifier having noise figure of 6 dB and dispersion compensating fiber. Table 1 lists the various parameters of channel.

The decoder is designed opposite to encoders respectively to realign the pulses. Receiver also consists of photo detector possessing cut-off frequency of 8 GHz. The system is redesigned for twenty numbers of users. All practical impairments like dispersion, dispersion slope etc. is included while analyzing the performance of system.

3 Results & Discussions

Using simulation set up, we have investigated the performance of OCDMA system for various modulation formats like NRZ, RZ, CSRZ and duo-binary at 10 Gbps for two types of optical encoders.

Case 1: OCDMA system using optical filter and time delay as optical encoder

In this case the performance of system is investigated for combination of filter and time delay components as encoder. Fig. 2 demonstrate the graphs for investigations of Q^2 (dB) vs power, received optical power vs. input power, received optical power
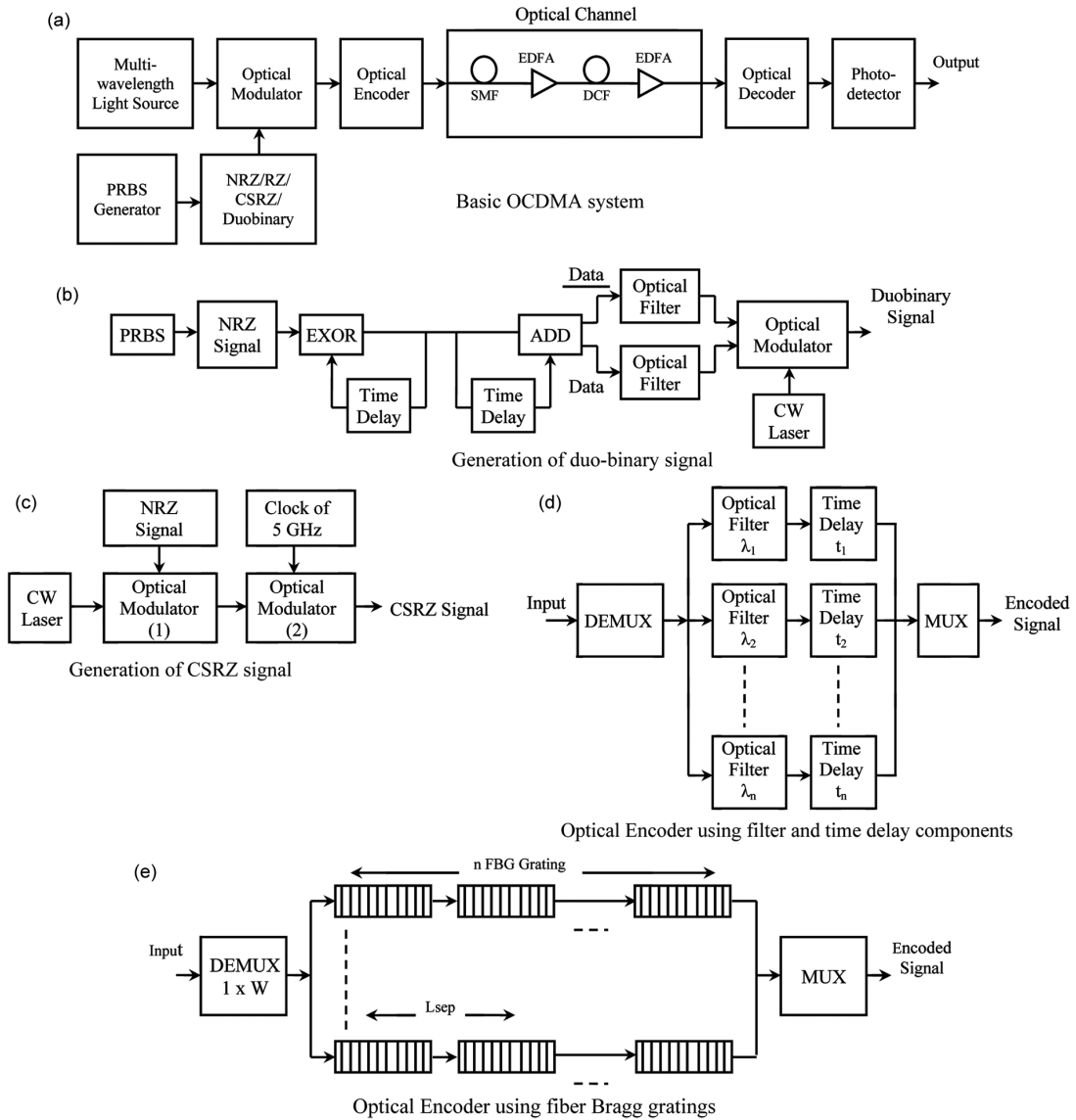
Fig. 1 (a-e) — (a) Basic OCDMA system, (b) Generation of duo-binary signal, (c) Generation of CSRZ signal, (d) Optical Encoder using filter and time delay components & (e) Optical Encoder using fiber Bragg gratings.

Table 1 — Channel Parameters		
Parameters	SSMF	DCF
Fiber attenuation (dB/km)	0.2	0.5
Length (km)	60	12
Dispersion (ps/nm/km)	16	-80
Dispersion Slope (ps/nm^2.km)	0.06	-0.30
Effective core area (μm^2)	60	25
Non linear refractive index n_2	$12e^{-22}$	$48e^{-22}$

vs. length of fiber and optical SNR vs. length of fiber. From the graph Fig. 2(a), it has been analyzed that at a input power of 6 dB, maximum Q-factor can be achieved. Fig. 2(b) shows the plot of received optical power vs. input power. It has been observed that received optical power decreases as a function of length of optical fiber linearly from (-27 to -30); (-32 to -37); (-24 to -28) and (-36 to -40) for duo-binary, RZ, CSRZ and NRZ modulation formats respectively in Fig. 2(c) Similarly from Fig. 2(d) it is reported that value of OSNR (dB) also decreases with distance from (34-29); (33-28); (34-28.5) and (26.5-23) for CSRZ, RZ, duo-binary and NRZ formats respectively. Therefore it is clear that CSRZ format is most suitable format for OCDMA system when filter and time delays are used a encoders. Fig. 3 indicates the eye diagrams for these modulation formats.

Here, the maximum opening of eye in case of CSRZ in comparison to NRZ, RZ and duo-
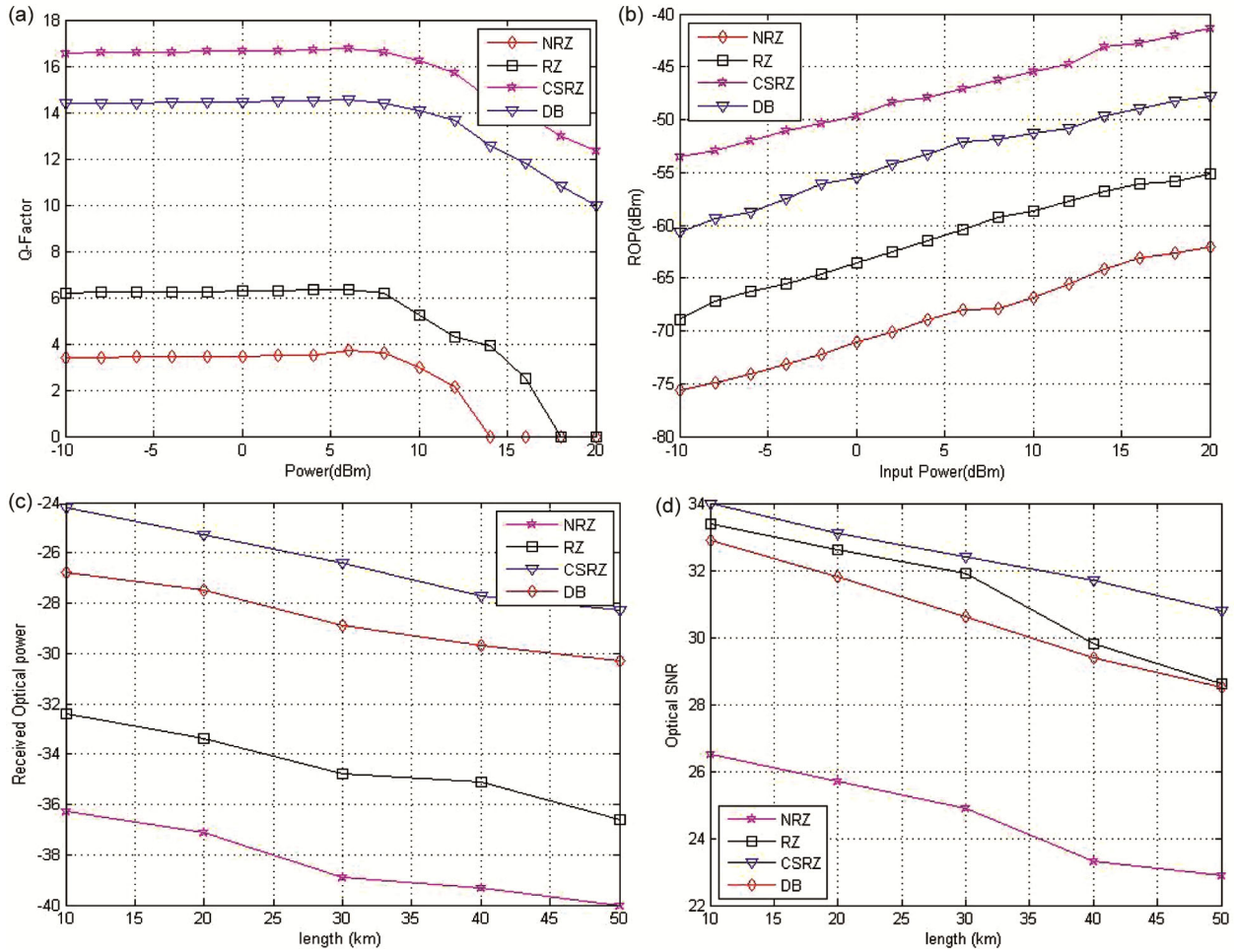
Fig. 2 — For system using filter & time delay as optical encoder (a) Q-factor vs. input power (b) ROP vs. input power (c) ROP vs. length of fiber (d) Optical SNR vs. length of fiber.

binary clarifies the robustness of this format to the system.

Case 2: OCDMA system using Fiber Bragg Gratings (FBG's) as optical encoder

In this case we have used FBG's as encoders and reported the performance of system for various modulation formats. The various investigations reveal that maximum $Q^2(dB)$ of the order of (17.7-13.8); (11.8-8); (7-1) and (4-0) is achieved in case of duo-binary, CSRZ, RZ and NRZ modulation formats respectively at a power level of 6 dB and 20 dB. Fig. 4(a) shows plot of Q-factor vs. average input power. From the graph, it has been analyzed that at a input power of 6 dB, maximum Q-factor can be achieved. But as the input power level further increases, various fiber impairments degrade the system performance. Fig. 4(b) presents the plot of received optical power vs. input power. With an increase in input power, output optical power also increases. For an input power from (-10 to 20 dBm), the output optical power (dBm) varies from (-80 to -65); (-74 to -59); (-52 to -45) and (-63 to -52) for NRZ, RZ, duo-binary and CSRZ modulation formats respectively. It shows highest power in case of duo binary format. Fig. 4(c) & (d) demonstaretes the plot of received optical power and optical signal-to-noise ratio with respect to length of the fiber.

It has been observed that the value of OSNR (dB) decreases with distance from (31.8-26.8); (28-25); (27.9-23.8) and (24.2-22) for duo-binary, CSRZ, RZ and NRZ formats respectively. Similarly it is reported that received optical power also decreases as a function of transmission distance linearly from (-25 to -28); (-32 to -34); (-28 to -31) and (-33 to -36) in case of duo-binary, RZ, CSRZ and NRZ modulation formats respectively. Therefore, duo-binary format is a promising format for OCDMA system. When fiber Bragg gratings are used as encoders, Fig. 5 indicates
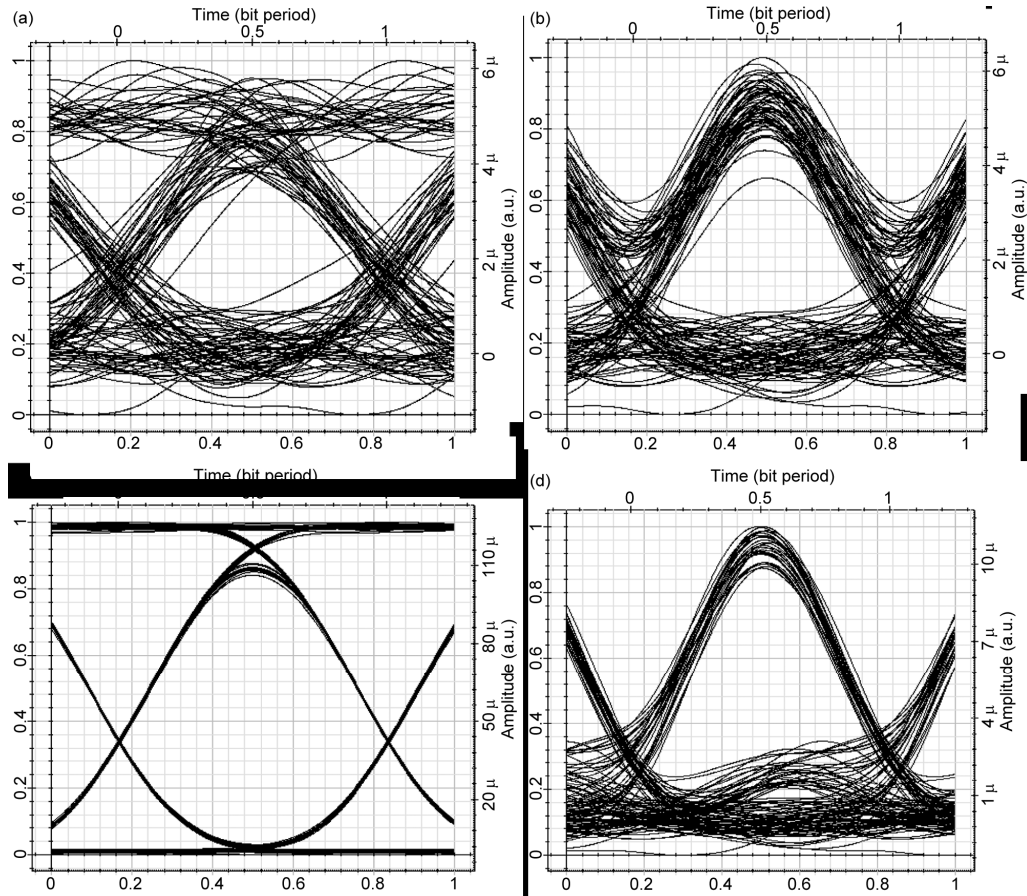
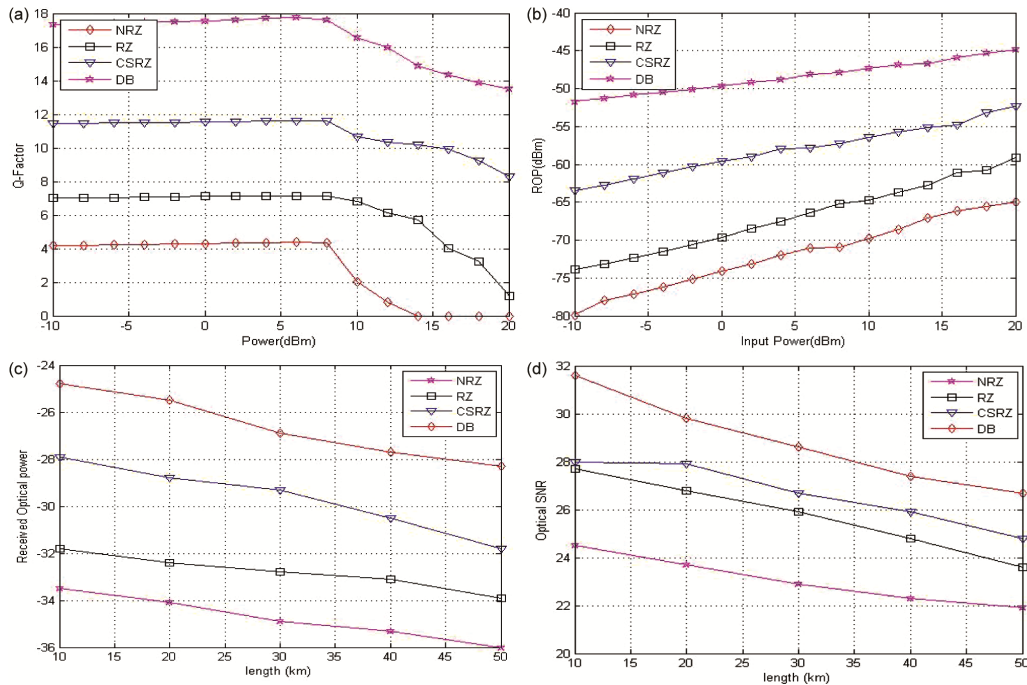Fig. 3 — Eye diagrams (a) NRZ (b) RZ (c) CSRZ (d) duo binary.

Fig. 4 — For system using FBG as optical encoder (a) Q-factor vs. input power (b) ROP vs. input power (c) ROP vs. length of fiber (d) Optical SNR vs. length of fiber.
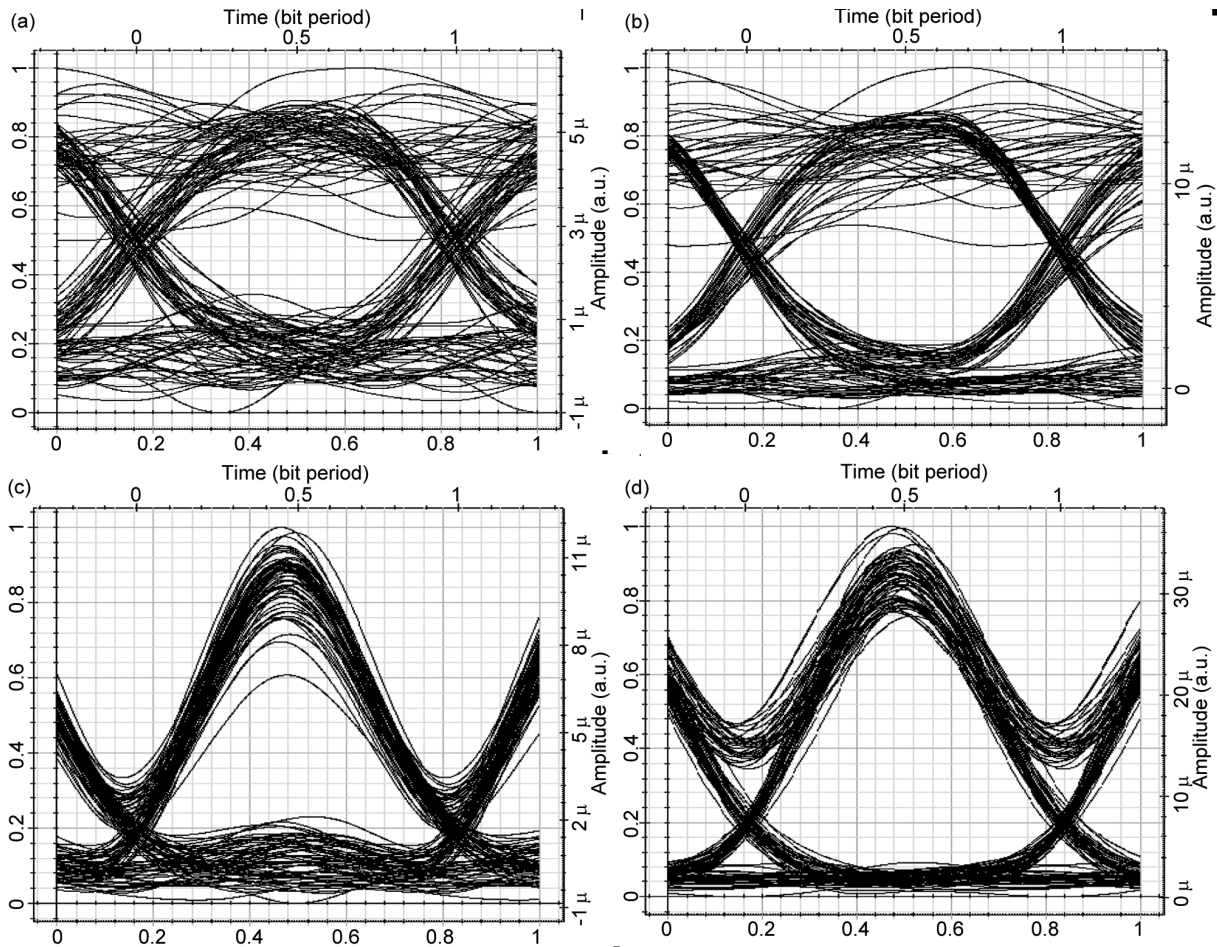
Fig. 5 — Eye diagrams (a) NRZ (b) RZ (c) CSRZ (d) duo-binary.

the eye diagrams for NRZ, RZ, CSRZ and duo-binary modulation formats. Again, maximum eye opening in case of duo-binary modulation format proves its edge in comparison to NRZ, RZ and CSRZ to the system.

4 Conclusions

In this paper, the performance of optical CDMA system using two dimensional (2D) matrix wavelength/time codes with filter in combination with time delay as encoder and fiber Bragg gratings as encoder for various modulation formats NRZ, RZ,CSRZ and duo-binary is analyzed and compared. The investigations reveal that for filter and time delay as optical encoder, CSRZ modulation format gives optimum performance and for FBG's as encoder duo binary modulation format shows an edge in comparison to the other formats. Therefore, CSRZ and duo binary modulation formats indicate better link performance for OCDMA system depending upon system requirement.

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