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Full Length Research Paper

Development of narrow band spectral-sliced wavelength division multiplexing (WDM) system and its performance in optical access networks

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In this paper, we have proposed a narrow band spectral-sliced wavelength division multiplexing (WDM) system and investigated its performance for optical access networks application. In the proposed system, the low cost light emitting diodes (LEDs) are used as the broad band light source. The system performance investigation was carried out using non-return-to-zero (NRZ) and return-to-zero (RZ) modulation format by OptiSystem Software, Version 7.0. We used two network system models, the first one used RZ pulse generator and the second one used NRZ pulse generator, and both systems are tested without any amplifier. It was found that NRZ pulse generator signal performance is better than those of RZ pulse generator. The proposed system network simulation runs at different bit rates (BR), such as 622 Mb/s, 1 and 1.5 Gb/s, respectively. We ascertained from the network simulation results that the proposed system exhibits better performance at 622 Mb/s as compared to others bit rates. Furthermore, the overall system performances are characterized through bit-error-rate (BER) and BR including the received optical power at various BR. In this analysis, the BER performance has been considered as the main system performance criterion. It has been shown, that the proposed method with NRZ modulation technique provides improved transmission performance as compared to the return-to-zero modulation technique.

Key words: Non-return-to-zero/Return-to-zero modulation format, spectral slicing, wavelength division multiplexing (WDM).

INTRODUCTION

Wavelength division multiplexing (WDM) system is recognized as one of the promising technologies for transmitting multiple signals of different wavelengths over a single optical fiber (Yong, 1964). However, the conventional WDM system can hardly be applied to systems that require high data transmission rate regardless of short haul or long haul transmission line. Furthermore, the demands of high data transmission are increasing day-by-day for optical access networks, such as local area network (LAN) and metropolitan area network (MAN) (Thiele et al., 1999). To address these issues, we need to increase the channel bit rates of several Mb/s over a distance of several kilometers. Accordingly, it is very much essential to develop a new technology that can fulfill the current demands of high data transmission rate.

Meanwhile, researchers and scientists introduced a promising technology called “Spectral Slicing” that brings the WDM technology one step more ahead of advanced technology (Wagner and Lemberg, 1989; Reeve et al., 1988). In this technology, the light emitting diodes (LEDs) is employed as the low cost broad brand source (BBS) to play the role of light sources instead of costly laser diodes (Young, 1964). The LED has high broadband spectrum, which can be sliced spectrally into many independent signals with equal channel spacing as

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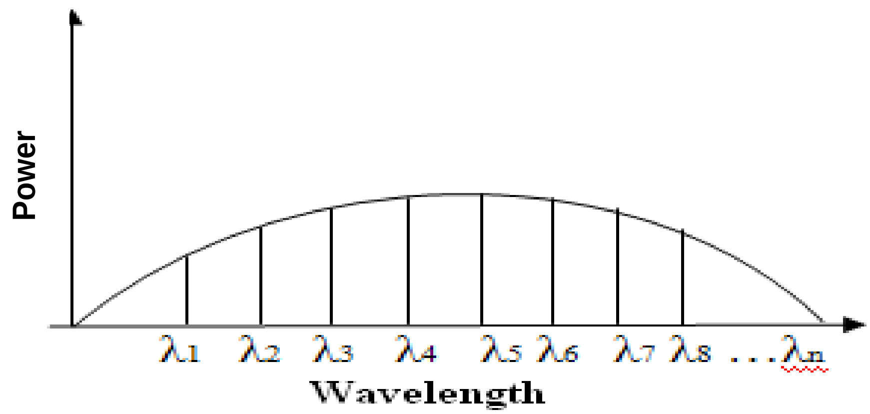

Figure 1. Spectral slicing diagram with equal channel spacing.

shown in Figure 1.

Literature survey reveals that the selection of optimum channel spacing between the two sliced spectral is a very critical task (Lee et al., 1993). We found that 0.8 nm channel spacing is used in spectral-sliced WDM system, experimentally (Shtaif et al., 1998). So far, we know that 0.4 nm channel spacing spectral-sliced WDM system is still under study and investigation stage (Eiste et al., 1997). We then selected 0.4 nm channel spacing for our system, which is referred to as narrow band spectral-sliced WDM system.

In this paper, we developed a narrow band spectral-sliced WDM system and investigated its performance by simulation using non-return-to-zero (NRZ) and return-to-zero (RZ) modulation format at different bit rates, such as 622 Mb/s, 1 and 1.5 Gb/s, respectively. We used NRZ and RZ modulation format, because these two modulation formats are commonly used in WDM system as well as cost-effective systems (Shtaif et al., 2000). Moreover, the NRZ is the simplest one that can be obtained by switching a laser source between “ON” or “OFF” (David and Alan, 2005). Conversely, the RZ is a bit complex and carries a line code that is used in telecommunication signals and the signals drops to zero between each pulse (Jianjun, 2003). The sample data signals format of NRZ and RZ are illustrated in Figure 2a and b.

This remaining parts of this paper is organized as follows. Subsequently, the study shows the materials and methods used in developing the system, after which the results obtained were discussed. This was followed by a critical evaluation and comparison in the study's discussion. Finally, some concluding remarks were made.

MATERIALS AND METHODS

Proposed system model

The proposed narrow band spectral-sliced WDM system block diagram is as shown in Figure 3. The proposed system consists of three sections, namely the transmitter (TM), fiber and the receiver (RC) section. In the TM section, a low cost broadband light source light emitting diodes (LEDs) is used as a light source for transmitting the signal. The broadband light source operation wavelength started from 1550 nm, and the total bandwidth is 5 nm. The DC power is used as the input power for the light source. The average input power of light source is emitted from 1 to 6 dBm. In the transmitter side of the proposed system, the LED's spectrum was sliced into four input signals using a demultiplexer. Each sliced channel has spectral width of 0.4 nm including 2 dB insertion loss and slicing component like optical filter. The sliced signal is then transmitted to the point-to-multipoint (P2MP) in each optical line terminal (OLT), which consists of three components, such as pseudo random bit sequence (PRBS, 2^{15}-1) generators, NRZ pulse generators and Mach-Zehnder modulator. The modulated signal is combined by multiplexer, where each spectral width is same as well as insertion losses. The single mode fiber (SMF) is used to transmit the modulated signal towards to the receiver. In this simulation experiment, the used fiber parameter values are taken from the data which are based on the G.652 non dispersion shifted fiber (NDSF) standard, this includes all fiber parameter, such as group delay, group velocity, attenuation α (that is, 0.25 dB/km), polarization mode dispersion (PMD, that is, 18 ps/√km), non linear effects, such as four wave mixing (FWM) and self phase modulation (SPM), which are all wavelength dependent (Table 1). All these parameters were activated during simulation. The dark current values was 5 nA and the thermal noise co-efficient was 1.8×10^{-23} W/Hz for each of the photodetectors.

In the receiver (RC) section, the transmitted signal from the fiber is divided by demultiplexer. The demultiplexer losses, such as the insertion losses, are considered as 2 dBm. We have chosen four positive intrinsic negative (PIN) photodetector to detect the incoming signal. The optical power meter is connected with channel which is divided from demultiplexer to measure the optical output power, which is considered as a received power of the system. The average received power of this system was between -17.589 and -29.882 dBm, which is considered optimum received power. We have then used a low pass filter (LPF) to detected signal. Finally, we used eye-diagram analyzers to evaluate the performance of each channel signal.

Simulation setup

The simulation setup for 4-channel spectral-sliced WDM system with 0.4 nm channel spacing is illustrated as shown in Figure 4. We

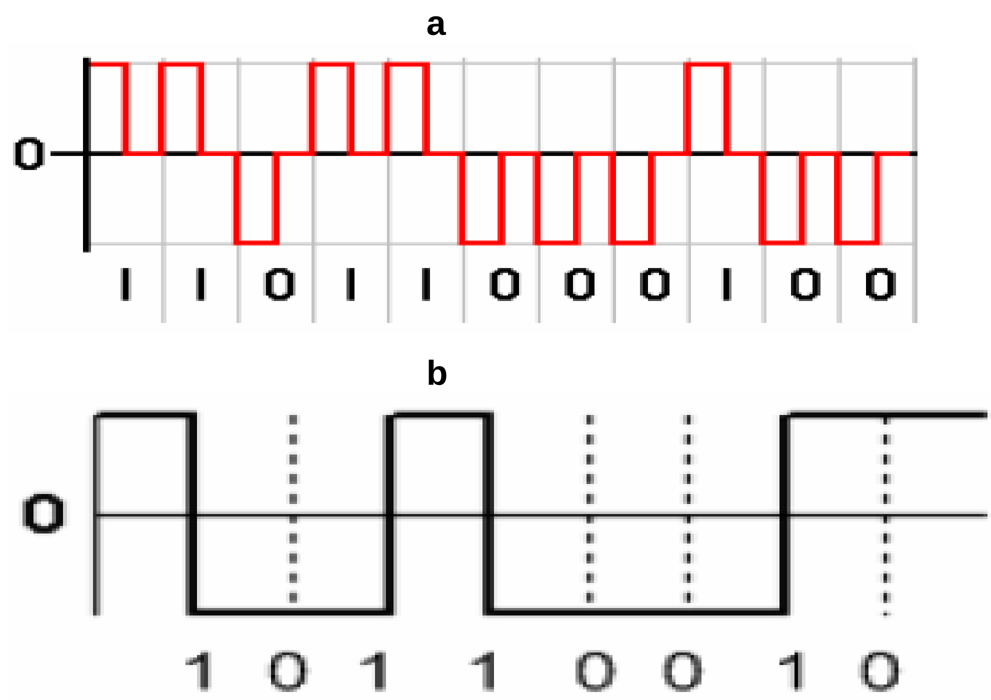

Figure 2. Data signal waveforms of (a) NRZ modulation format and (b) RZ modulation format.

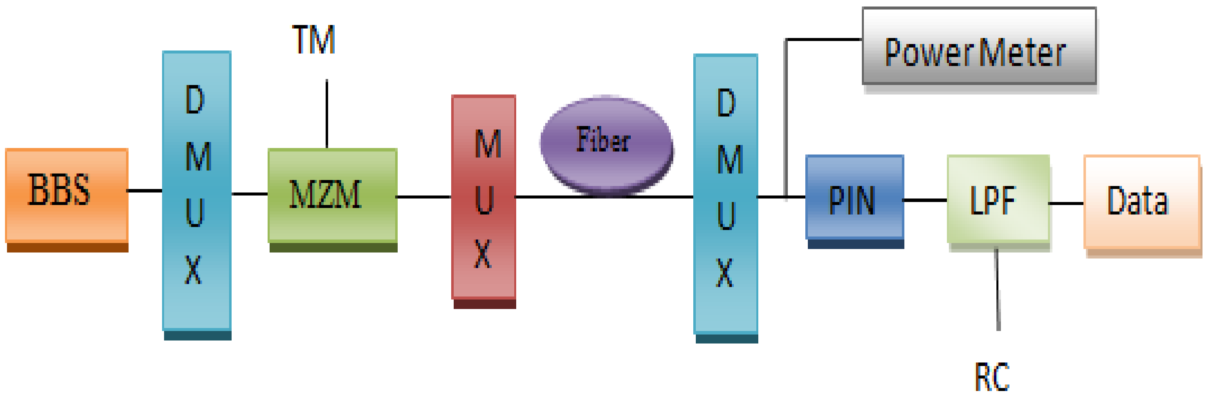

Figure 3. Block diagram of the proposed narrow band spectral-sliced WDM system, composed of 4-channels with 0.4 nm channel spacing.

Table 1. Summary of parameters used in simulation.

Data rate per channel	622 Mb/s
Transmission distance	30 km
Channel spacing	0.50 GHz
Output power	(-17.589 to - 29.882) dBm
Insertion loss	0.25 dB
Multiplexer/Demultiplexer insertion loss	2 dBm
Fiber attenuation	0.25 dB/km
BBS frequency	1550 nm
BBS bandwidth	3 nm

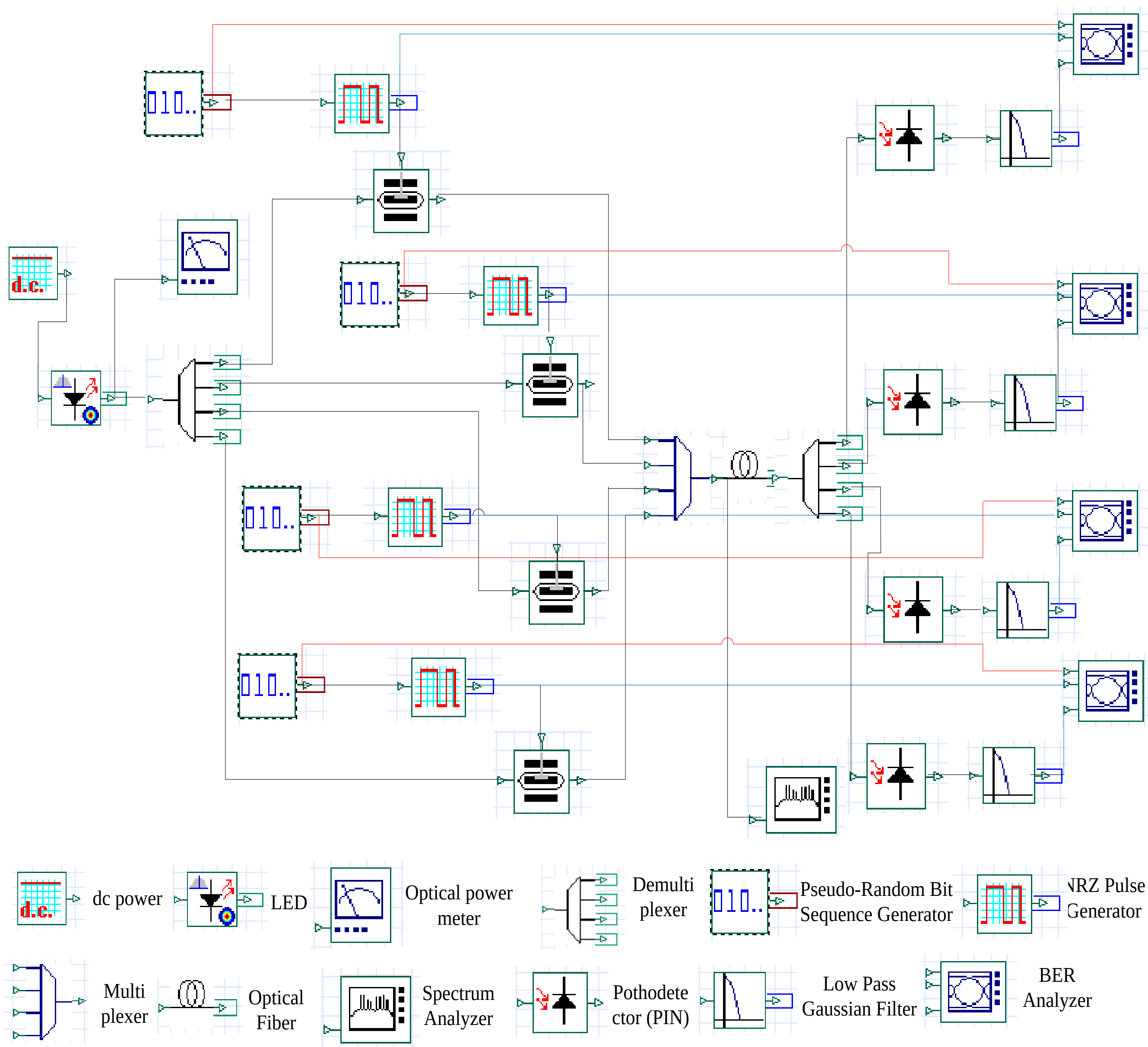

Figure 4. Schematic diagram of simulation setup for 4-channel narrow band spectral-sliced WDM system.

conducted simulation by using the simulation software, OptiSystem Version 9.0. The simulation was carried out at different data bit rates, such as 622 Mb/s, 1 and 1.5 GB/s for a 30 km distance with ITU-T G.652 standard SMF. We choose 30 km distance for transmitting multiplexed signal, because the multiplexed signal can be transmitted over 30 km distances through SMF without any amplifier (Shtaif et al., 2000). Furthermore, single mode fiber is used to minimize the influence of dispersion.

All the fiber parameters, such as attenuation, group delay, group velocity dispersion, dispersion slop and non-liner effects are activated during the simulation. The zero-dispersion of wavelength and the dispersion slope of SSF are 1550 nm and 0.075 ps/$\sqrt{km.nm}$. The noise generated at the receivers was set to be random and totally uncorrelated. The dark current value was set as 5 nA, and the thermal noise coefficient was 1.8 × 10^{-23} W/Hz for each of the photo-detectors. The average fiber loss is about 0.2 dBm, including the splicing loss. The system insertion loss, including multiplexer/demultiplexer is taken in the account as 0.25 and 2 dBm, respectively.

RESULTS

The analysis of the simulation results is illustrated in Figures 5 and 6. As shown in Figure 5a, b and c, the BER value of NRZ modulation format is better than RZ modulation format at the lower bit rates as well as compared to the higher bit rates. Figure 6 reveals this fact more clearly. In order to understand and clarify more

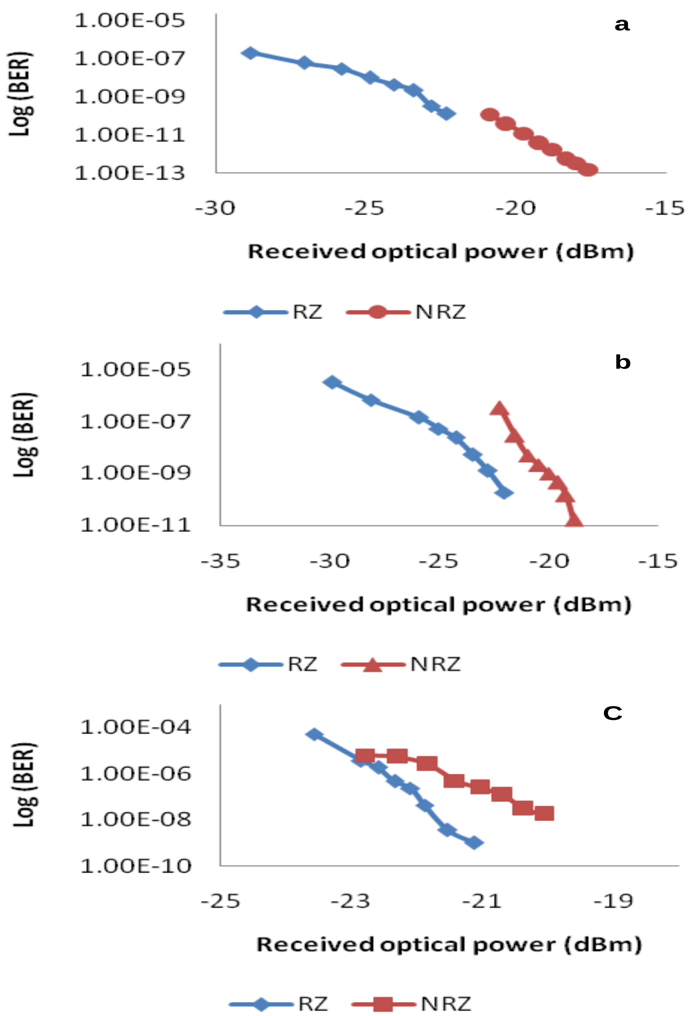

Figure 5. BER comparison between RZ and NRZ modulation format at (a) 622 Mb/s, (b) 1 Gb/s and (c) 1.5 Gb/s bit rates. The BER was measured at channel-1, while all 4-channles were transmitting data over a 30 km fiber.

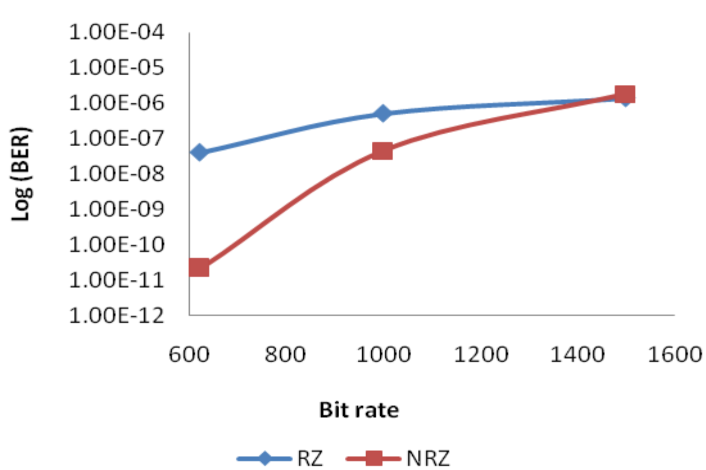

Figure 6. BER measured at different bit rates under RZ and NRZ modulation format.

clearly, Table 2 was made using Figure 5, b and c, which summarizes the minimum value of BER for both RZ and NRZ modulation format at three different data bit rates, such as 622 Mb/s, 1 and 1.5 Gb/s.

Looking at Table 2, the minimum BER value of NRZ modulation format at 622 Mb/s data bit rates is $2.23e^{-11}$, which is less than the standard acceptable BER value ($\leq 10^{-9}$). In addition, the minimum BER value of RZ modulation format at the same data bit rates of 622 Mb/s is $4.13e^{-08}$, which is larger than the standard acceptable BER value ($\leq 10^{-9}$).

We further notice from Table 2 that the minimum value of BER for both NRZ and RZ modulation formats at 1 and 1.5 Gb/s is always greater than the standard BER value ($\leq 10^{-9}$). It seems that our proposed narrow band (0.4 nm channel spacing) spectral-sliced WDM system can provide acceptable standard BER only under NRZ modulation format at lower bit rates of 622 Mb/s. The system performance under both RZ and NRZ modulation format at higher bit rates, such as 1 and 1.5 Gb/s are not applicable for practical consideration.

DISCUSSION

BER has been considered as the system performance criterion for comparison. Then, we decided to measure the BER against received optical power for 30 km transmissions. Accordingly, we measured BER against received power at different bit rates, such as 622 Mb/s, 1 and 1.5 Gb/s using both RZ and NRZ modulation format, which are as shown in Figure 5a, b and c, respectively. In addition, we also measured BER against system bit rates using both RZ and NRZ modulation format, which are as shown in Figure 6.

It is also noticeable that the proposed system under NRZ modulation format requires a bit more power as compared to RZ modulation format as shown in Figure 5. However, the received signal quality under NRZ modulation format is better than that of RZ modulation format, which is ascertained by eye diagrams and RF spectrum signal of both RZ and NRZ modulation format as shown in Figures 7 and 8, respectively. We can see from Figure 8 that the frequency bandwidth of NRZ modulation format is -24 dBm powers, which is equal to the 40% of the bandwidth of RZ with -28 dBm power.

Since the main objective of this study is to compare different modulation format with different data rates, which has been achieved by the proposed system. The results are obtained using simulation analysis and it has been compared among different bit rates. It was found out that the system BER performance is good at 622 Mb/s. Therefore, the proposed system can be applicable for future optical access networks.

Conclusion

Spectral-slicing is a powerful technique to establish a low

Table 2. Comparison of BER between RZ and NRZ modulation format at different bit rates.

622 Mb/s		1 Gb/s		1.5 Gb/s	
RZ	**NRZ**	**RZ**	**NRZ**	**RZ**	**NRZ**
4.13e-^{08}	2.23e-^{11}	5.15e-^{07}	4.53e-^{08}	1.41e-^{06}	1.82e-^{06}

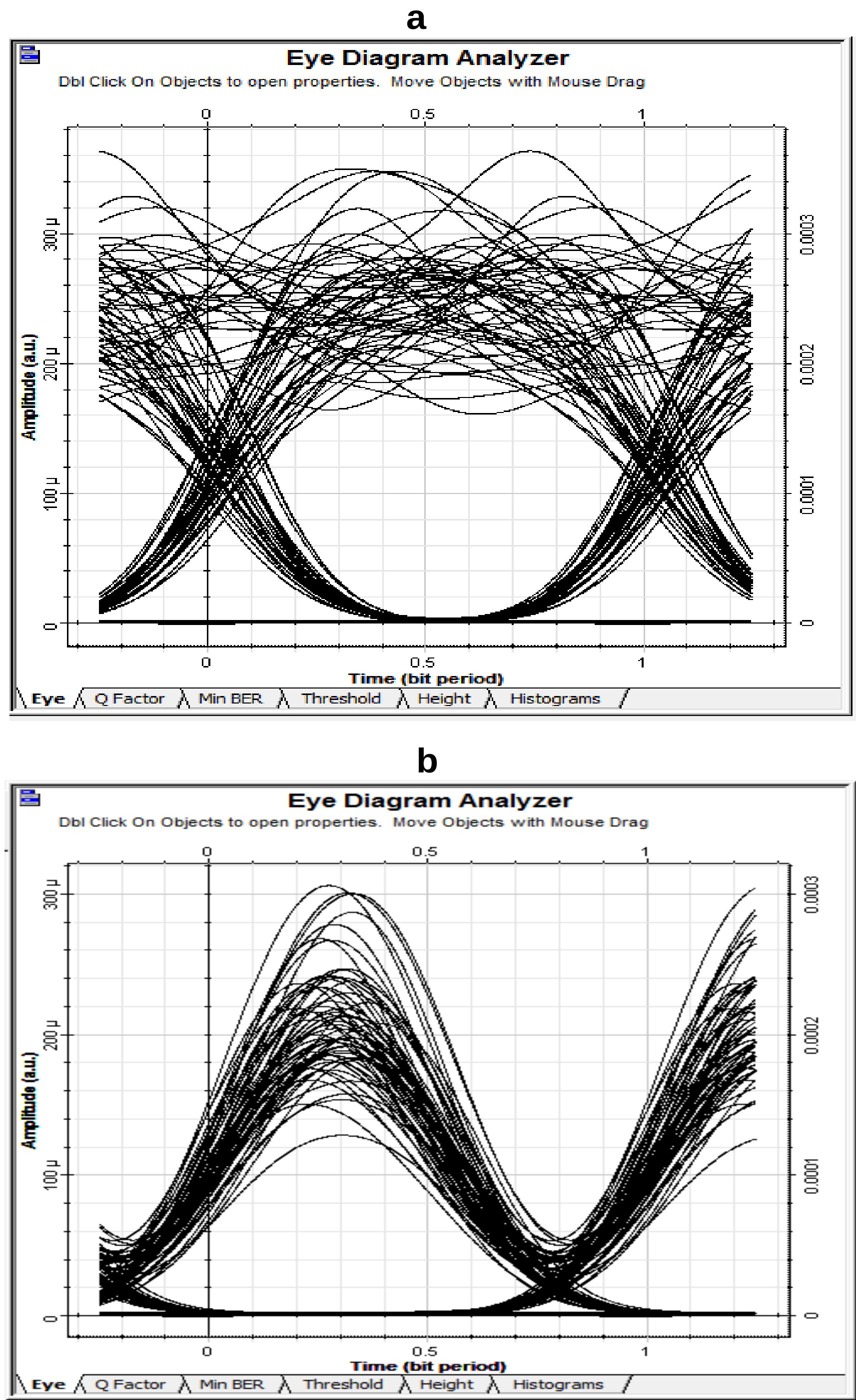

Figure 7. Eye diagrams measured at 622 Mb/s system bit rates under (a) NRZ and (b) RZ modulation format.

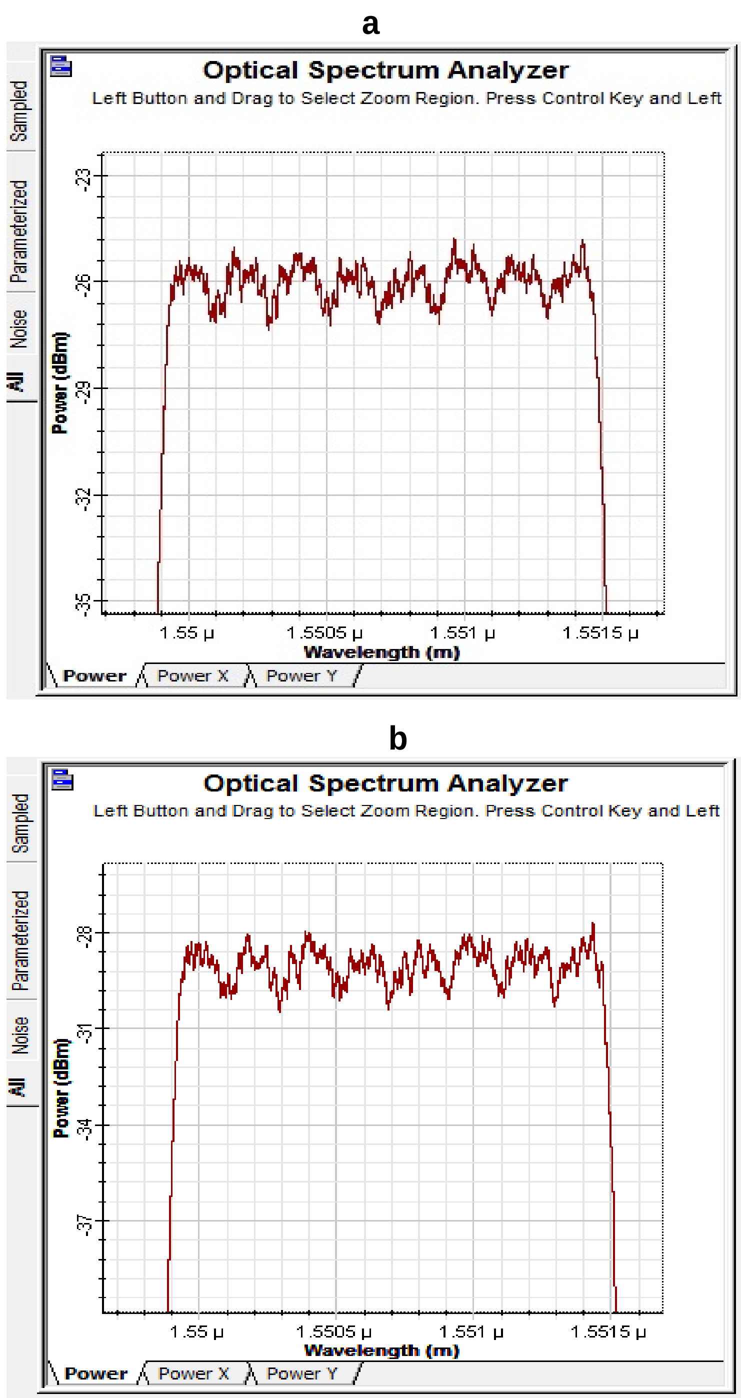

Figure 8. RF spectrum signal of broad band light source, (a) NRZ and (b) RZ modulation format.

cost narrow band channel spacing WDM system. In this paper, our proposed narrow band spectral-sliced WDM system runs simultaneously on four channels with 0.4 nm channel spacing at 622 Mb/s bit rate. We found by network simulation, that the NRZ modulation format performs well at 622 Mb/s system bit rates as compared to RZ modulation format and 1 and 1.5 Gb/s system bit rates. The system performance has been investigated using simulator and its investigation was carried out by considering the system BER against received optical power at various system bit rates. Furthermore, we have investigated the signal quality of the received signal by using eye diagrams and RF spectrum signals. The results obtained using NRZ and RZ modulation format were compared. The comparison results ascertained that the proposed system model provides better signal quality under NRZ modulation format at 622 Mb/s bit rates. Therefore, the proposed system would then be a promising solution to the next generation optical access networks, such as metro-area-network (MAN), local-area-network (LAN), fiber-to-the-building (FTTB) and fiber-to-the-home (FTTH) applications.

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