

## Research Article

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# RZ Line Coding Scheme With Direct Laser Modulation for Upgrading Optical Transmission Systems

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**Abstract:** This study reports the efficient use of a direct laser modulated response measured with the return-to-zero coding scheme in optical transmission systems. The measured direct laser modulated response has a bit rate of 1.2 Gbps for an optical fiber cable of a transmission length of 10 km. The eye diagram analyzer is used to calculate the maximum quality factor and minimum bit error rate of the proposed model. The maximum quality factor is 531.2, and the minimum bit error rate tends to zero for the same optical fiber channel length compared with that of the previous model. The proposed model provides better results than the previous model. The figures of the proposed model are more stable than those of its previous counterpart. Bit error rate approximately tends to zero in the proposed model.

**Keywords:** Max. Q-factor, Optical fiber channel, Laser response, Return-to-zero coding, Cable length

## 1 Related works

Many recent studies have proposed designs to enhance transmission capacity to meet end-user demand for broadband services in social networking, high definition video-on-demand, and cloud storage and computing. To meet this goal, optical injection technology has emerged to serve as multiple wavelength-division-multiplexed

(WDM) transmitters. WDM passive optical networks (WDM-PONs) are considered a promising solution for broadband PONs, in which the capacity of optical networks is enlarged by transmitting different wavelengths at the same time. Cavity design was considered for matching the need for the dense wavelength-division-multiplexed channel spacing in high speed optical networks [1]. Return-to-zero (RZ) and non-return-to-zero (NRZ) data and its encoding response have been investigated [2–4]. Although substantial efforts focusing on long-haul access networks are underway, the transmission distance is limited to approximately 20 km at a data rate of 10 Gb/s because of the chromatic dispersion related to direct modulation [5].

Therefore, transmission distance was accounted for in these studies. Light source devices, especially tunable injection lasers, play the most important role in this field [6–8]. In general, two kinds of devices are used as light sources: lasers and light-emitting diodes. In addition, light can be produced in two ways: by spontaneous emission [9–14] and simulated emission. Laser light is an example of the simulated emission of radiation used for light amplification, whereas fluorescent light is an example of spontaneous emission of radiation. There are many types of lasers, including semiconductor laser diodes, fiber lasers, and gas lasers [11–17]. Semiconductor laser diodes are unsuitable for application over extended distances or for wavelength multiplexing. Fiber lasers exhibit important characteristics such as high power output, low noise, and preselected wavelength. A gas laser is a simple type of laser, but it is not used in modern communications [18–24]. Stimulated emission by a recombination of injected carriers has been encouraged for semiconductor injection lasers [25–30]. The provision of an optical cavity in the crystal structure provides photon feedback [15, 31–33]. This characteristic provides numerous advantages for injection lasers over other semiconductor laser sources. Good spatial coherence allows the output to be focused by a lens onto a spot with a greater intensity than dispersed unfocused emission [34–37]. This permits efficient coupling of the optical output power into the fiber even when

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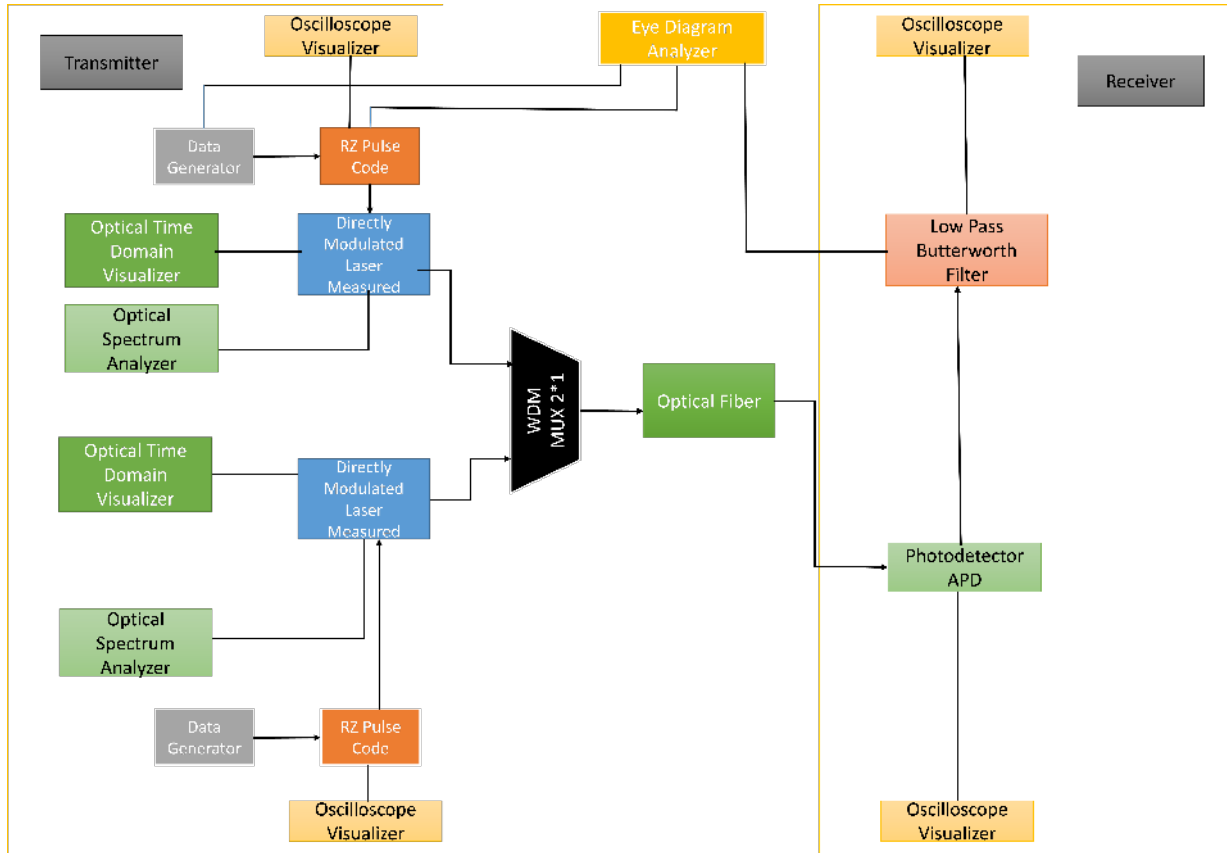


Figure 1: Simulation model used in this work.

it has a low numerical aperture. Spatial fold matching to the optical fiber can be obtained with the laser source but not with an incoherent emitter [38–40].

## 2 Model description and research method

The previous model [13] comprises three main parts, namely a transmitter with a laser rate equation as the optical source, a pseudo-random bit sequence as a generator, and an NRZ pulse code. In the proposed model, we replace the laser rate equation with two directly modulated lasers passing through a wavelength-division multiplexing multiplexer (WDM MUX  $2 \times 1$ ). We also replace the NRZ pulse code with the RZ pulse code, and the pseudo-random bit sequence is substituted by a user-defined bit sequence generator. The receiver of the previous model contains a photodetector PIN and low-pass Bessel filter [13], but in the proposed model we replace the photodetector PIN with a photodetector avalanche photodiode (APD) and the Bessel filter with a low-pass Butterworth filter.

An eye diagram analyzer is used to calculate the maximum quality factor (max Q-factor) and the minimum bit rate (BER). To calculate these two parameters, we must connect the three inputs of the eye diagram analyzer. In this system, we connect the first input with the user-defined bit sequence generator at the transmitter. The second input is connected with the RZ pulse code (also at the transmitter), and the third input is connected with the low-pass Butterworth filter at the receiver.

## 3 Performance analysis with discussions

The simulation results are obtained using the clarified simulation parameters in Table 1. Figure 1 shows the differences between the proposed and previous models. The proposed model comprises three parts. The first part is composed of a transmitter that contains a user-defined bit sequence generator with a bit rate of 1.2 Gbps and direct laser modulation source operated at 1552.52 nm (*i.e.*, a third-generation fiber optics system) as the optical source.

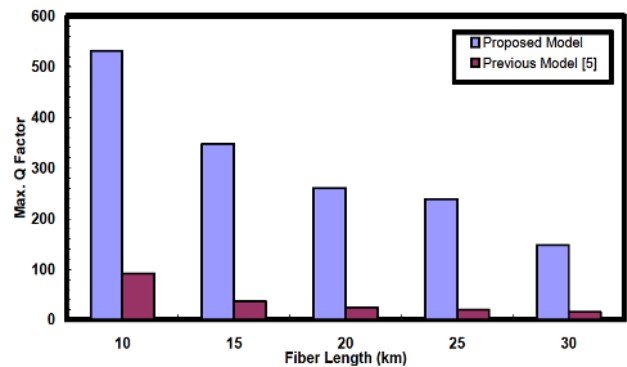
**Table 1:** List of operating simulation parameters for this study.

Value/unit	Main parameters	Components
1552.52 nm	Operating wavelength	Directly Modulated Laser Measured
10 dBm	Operating power	
10 dB	Extinction ratio	
300 mA	Maximum current	
1.2 Gbps	Bit rate	User-defined bit sequence generator
Exponential	Rectangle shape	RZ pulse code
10 GHz	Bandwidth	WDM MUX 2×1
10 km	Length	Optical fiber
0.2 dB/km	Attenuation	
1552.52 nm	Reference wavelength	
16.75 Ps/nm/km	Dispersion	
3	Gain	APD
10 nA	Dark current	
1 A/W	Responsivity	
0 dB	Loss	Low Pass Butterworth Filter
100 dB	Depth	

The system supports a bit rate of up to 5 Gbps with the RZ pulse code. These ingredients of the transmitter will repeat to pass it with the other ingredients in a cascade through a WDM MUX 2 × 1. The transmitter passes through a 10-km-long optical fiber that serves as the channel. The chosen length provides a good result.

The receiver contains the photodetector APD, which converts the light signal into electrical signals. It is operated at a gain of 3 and is connected to the low-pass Butterworth filter, which is used to remove any ripples from the main signal. The eye diagram analyzer is used with the low-pass Butterworth filter to remove the ripples from the electrical signal originating from the avalanche light detector. The second input is taken from the RZ pulse code, and the third input is sourced from the data generator (the user-defined bit sequence generator). The eye diagram analyzer is used to calculate the max Q-factor and the minimum BER. The simulation variables used in this study are provided in Table 1.

Figure 2 clarifies the relation between the max Q-factor and the fiber cable length. When the cable length increases, the max Q-factor clearly decreases. Moreover, the direct modulated laser source provides a better result than the laser rate equations for the same fiber length. The results indicate that the max Q-factor is 531.12 and the minimum BER tends to zero for a fiber length of 10 km. The max Q-factor is 387.17 and the minimum BER tends to zero for a fiber length of 15 km. The max Q-factor is 260.169 and the minimum BER tends to zero when the fiber length equals 20 km. At a fiber length of 25 km, the max Q-factor

**Figure 2:** Max Q-factor versus cable length as per the previous and proposed models.

is 239.715, and the minimum BER tends to zero. The max Q-factor is 148.3 and the minimum BER tends to zero when the fiber length is 30 km.

Figure 3 shows the results of the calculations by the eye diagram analyzer with the directly modulated laser source along a cable length of 10 km. The max Q-factor is 531.12, and the minimum BER tends to zero. Both results apply to a cable length of 10 km as well as to a light source bit rate of 1.2 Gbps. Figure 4 displays the results of the calculations by the eye diagram analyzer and the directly modulated laser source for a cable length of 15 km. The max Q-factor is 348.17, and the minimum BER tends to zero. These results apply for a cable length of 15 km at a bit rate of 1.2 Gbps for the generator of a transmitter that passed

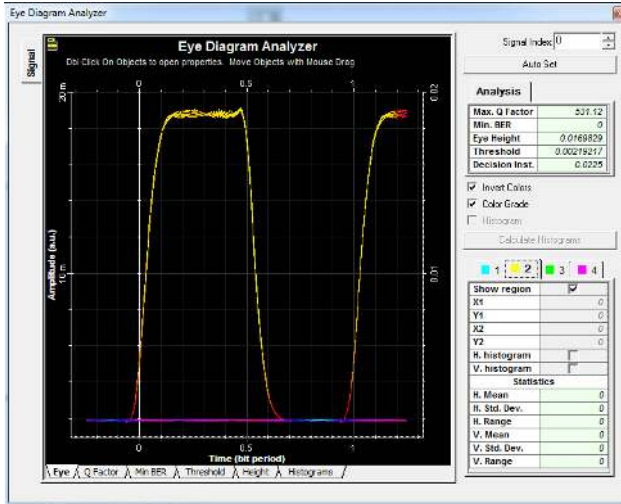


Figure 3: Results of the eye diagram analyzer with the directly modulated laser source along a cable length of 10 km.

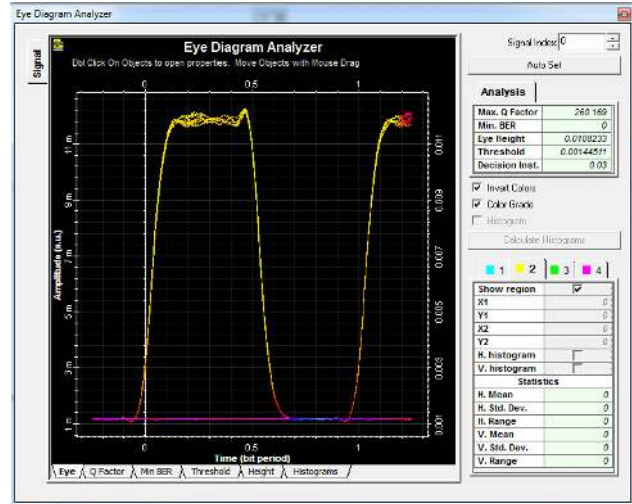


Figure 5: Results of the eye diagram analyzer with the directly modulated laser source along a cable length of 20 km.

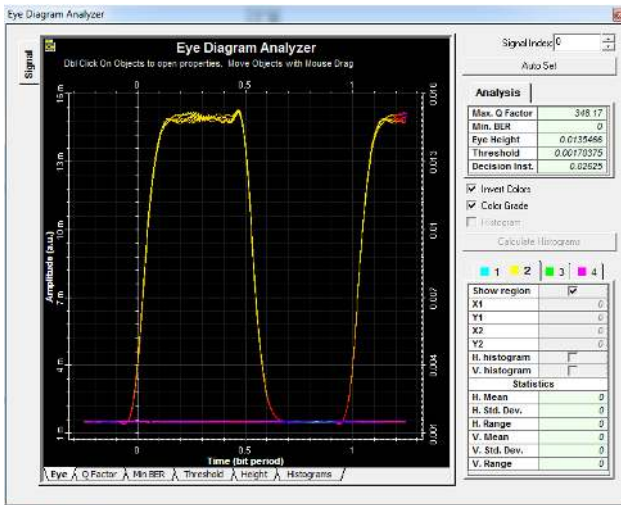


Figure 4: Results of the eye diagram analyzer with the directly modulated laser source along a cable length of 15 km.

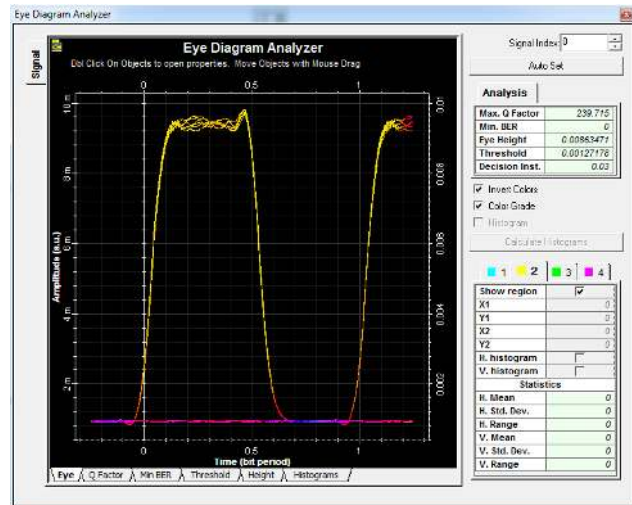


Figure 6: Results of the eye diagram analyzer with the directly modulated laser source along a cable length of 25 km.

through the optical source to the receiver within the fiber optical cable.

Figure 5 shows the max Q-factor calculated by the eye diagram analyzer. The max Q-factor is 260.169, and the minimum BER tends to zero. These values apply to a cable length of 20 km. Thus, the system provides good results at a length of 20 km. Figure 6 displays the results of the calculations by the eye diagram analyzer with the directly modulated laser source along a cable length of 25 km. The max Q-factor is 239.715, and the minimum BER is 0. These results apply for a cable length of 25 km, and the bit rate of the generator at the transmitter is 1.2 Gbps.

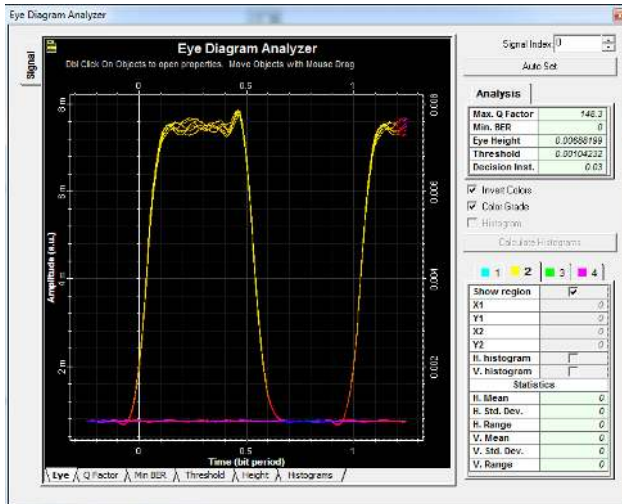
Figure 7 presents the results of the calculations by the eye diagram analyzer with the directly modulated laser

Table 2: Max. Q-factor dependence on cable length.

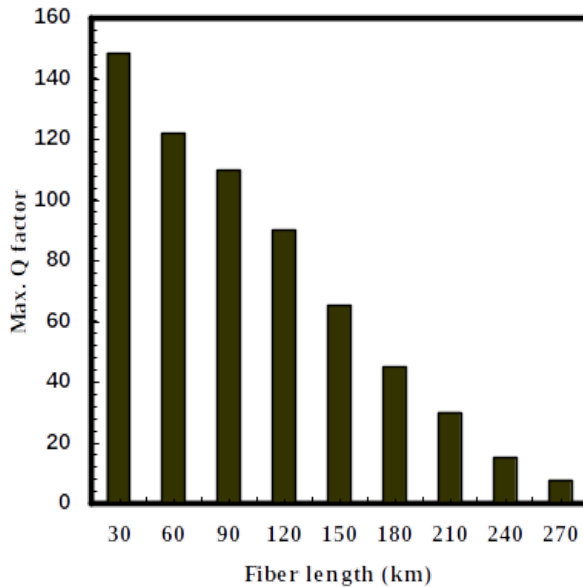
Max. Q factor (Proposed model)	Max. Q factor (Previous model [5])	Cable length
531.12	16.59	10 km
348.17	10.85	15 km
260.16	8.125	20 km
239.71	7.468	25 km
148.3	4.625	30 km

source for a cable length of 30 km. The max Q-factor is 148.3 and the minimum BER tends to zero. These results apply to a cable length of 30 km and a bit rate of 1.2 Gbps.





**Figure 7:** Results of the eye diagram analyzer with the directly modulated laser source along a cable length of 30 km.



**Figure 8:** Max Q-factor versus fiber optic cable length for the proposed model.

The proposed model thus outperforms the previous model with respect to the max Q-factor for a cable length of 30 km. These results are calculated by an electrical visualizer, namely the eye diagram analyzer, which uses the electrical signal filtered by the low-pass Butterworth filter.

Figure 8 shows how the max Q-factor varies by fiber cable length for lengths of up to 270 km. The results indicate that the max Q-factor degrades with the increase in cable length. The max Q-factor is approximately 7.543 for long distances (of up to 270 km), indicating the need for optical amplifiers. The dependence of the max Q-factor on

cable length is displayed in Table 2 for the proposed and previous models.

## 4 Conclusion

This study demonstrated the efficient employment of a directly modulated laser source with the RZ coding scheme to upgrade an optical transmission system with respect to the max Q-factor and minimum BER. The max Q-factor for the proposed simulation model reached 148.3, whereas that of the previous model was 4.625 for the same optic fiber channel length (up to 30 km). The proposed model allows the cable fiber length to be extended to up to 270 km, the corresponding max Q-factor and minimum BER being 7.543 and  $2.543 \times 10^{-12}$ , respectively.

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