# Performance Analysis of Optical Transmitters with the Non-ideal Mach-Zehnder Modulator

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## Abstract

This paper presents the performance analysis of 10[Gb/s] optical duobinary transmitters with the non-ideal Mach-Zehnder modulator which does not have exactly 50/50 splitting/combining ratios by computer simulations. For driving voltage ratios(=driving voltage/switching voltage) with smaller than 100[%], the transmission performance has been greatly affected by extension of LPF bandwidths. Nevertheless, the performance has been degraded when the driving voltage ratio is 100[%]. The smaller driving voltage ratios has, the more sensitivity improves by extension of LPF bandwidths under the asymmetry condition. But the driving voltage ratio with 80[%] has better bit error rate(BER) than those with 50[%] and 25[%].


Key Words : Optical Duobinary Transmitter, Mach-Zehnder Modulator(MZM), LPF(Low Pass Filter), Driving Voltage Ratio, Splitting/Combining Ratio, Asymmetry Ratio, Eye Diagram, Bit Error Rate(BER)

## 1. INTRODUCTION

Optical duobinary coding is an attractive coding method with a higher spectral efficiency and better tolerance of chromatic dispersion than non-return-to zero(NRZ) formats due to the narrower spectral bandwidth[1]. Up to now, various implementations of duobinary transmitters have been proposed[2-3]. However, the most cost-effective and simplest implementation involves the three level electrical signals generated by electrical low pass filters(LPFs) and the Mach-Zehnder modulator(MZM). Recent work has been studied how MZM driving voltages and LPF bandwidths affect shapes of optical pulses and the transmission performance of optical duobinary signals in linear regime. It was also demonstrated that the bandwidth of the LPFs influenced the pulse shapes of electrical signals severely and a 100[%] driving voltage operation did not necessarily yield the best performance result numerically and experimentally[4-5]. But all these works are based on the symmetry in signals and the modulator[6]. In this paper, we investigate the impact of asymmetry of splitting/combining ratios in MZM and the interplay between the driving voltages and the LPF bandwidths of duobinary transmitters when the asymmetry is included.

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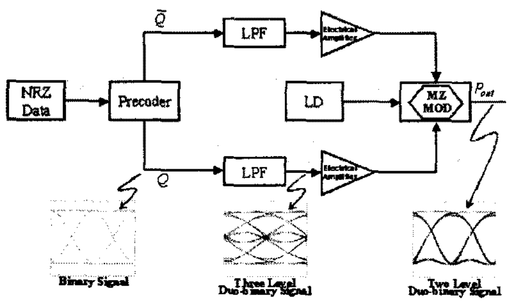



**Fig. 1. A schematic of optical duobinary transmitter**

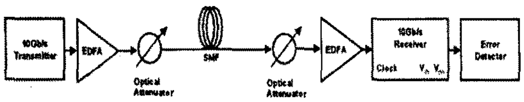



**Fig. 2 System used to optimize the transmitter**

## 2. SYSTEM DESCRIPTION

An optical duobinary transmitter consists of a precoder, two electrical amplifiers for the correct modulation voltage in the arms of MZM, two electrical LPFs to generate the three level signal for the optical duobinary coding, a continuous wave(CW) laser source, and a $LiNbO_3$ Mach-Zehnder modulator with two electrodes shown in Fig. 1. For driving the MZM in a push-pull manner, complementary 10[Gb/s] NRZ data are filtered using electrical filters and then properly amplified, so that we can convert a three level duobinary signal to the two level duobinary signal.

In order to simulate the transmission performance, we used the configuration shown in Fig. 2.

A non-ideal MZM and 5th order Bessel filters are used for the transmitter. The non-ideal MZM has splitting/combining ratios that are not exactly 50/50, and then the asymmetry ratio $\gamma$ of Y-branch is not exactly 1. Different driving voltages were applied to the dual electrode MZM so as to provide the driving voltage ratio of 25[%] to 100[%] normalized to the switching voltage($V_\pi$). Optical signals at 1,550[nm] wavelength were transmitted to 200[km] standard single mode fiber(SSMF) with dispersion parameter of D=17[ps]/([nm] · [km]). The signal was modulated at 10[Gb/s] with $2^7$ PRBS(pseudo-random binary sequence) using an MZM. The propagation along the fiber was modeled by the nonlinear Schrödinger equation and simulated using the split-step Fourier method. An erbium doped fiber amplifier(EDFA) with 32[dB] of gain and noise figure of 5[dB] was used to compensate the fiber loss in the link. The receiver is composed of PIN and an electrical filter modeled by the 4th order Bessel filter. To calculate the receiver sensitivity at 10[bit] error rate, we take into account the intersymbol interference(ISI) and set the ambiguity level of decision threshold to be 5[%][7].

## 3. SIMULATION RESULTS

Fig. 3 (a) and 3 (b) exhibit the simulated duobinary eye diagrams generated by the 2.7[GHz] LPF bandwidth and the asymmetry ratio $\gamma$=1(the symmetry condition) with 100[%] and 50[%] driving voltages, respectively.

The amplitude jitters of marks with the 100[%] driving voltage ratio are smaller than those with 50[%] driving voltage ratio due to the suppression of the fluctuations of electrical signals. Comparing with the 100[%] ratio, the ripples of spaces with the 50[%] driving voltage ratio are reduced by lowering the driving voltage ratio and the eye-opening is broadened horizontally. The asymmetry ratio $\gamma$=1.3 with 2.7[GHz] and 3.0[GHz] bandwidths for 100[%] driving voltages are presented in Fig. 4 (a) and 4 (b), respectively.

In case of the 3.0[GHz] bandwidth, the ripples of spaces are increased and the jitters of marks are

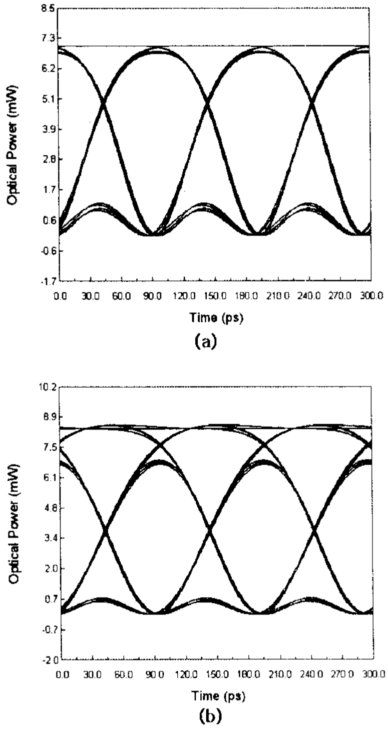



**Fig. 3. Eye diagrams at 0[km] based on 2.7[GHz] bandwidth and $\gamma$=1 with the driving voltage ratio (a) 100[%] (b) 50[%]**

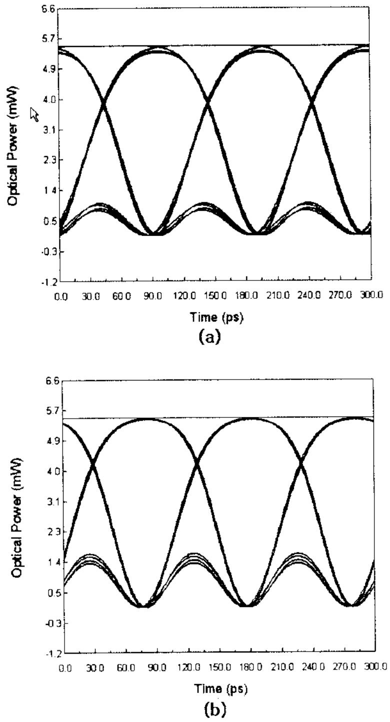



**Fig. 4. Eye diagrams at 0[km] based on $\gamma$=1.3 and 100[%] driving voltage ratio with the LPF bandwidth (a) 2.7[GHz] (b) 3.0[GHz]**

thicker than those of the 2.7[GHz] bandwidth. These cause a deterioration of the eye diagram under the asymmetry condition.

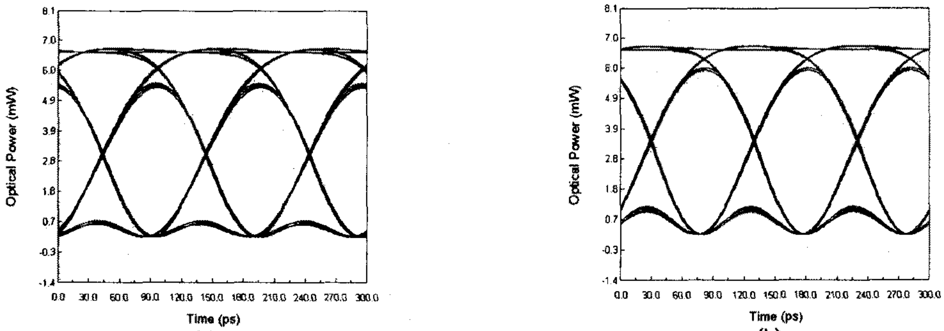
The asymmetry ratio $\gamma$ of Y-branch causes a finite extinction ratio and a non-zero residual chirp. The residual chirp $\alpha$ and extinction ratio $\epsilon$ can be calculated respectively, through the following equations[8].

$$\alpha = (1-\gamma^2)/2\gamma \qquad (1)$$

$$\gamma = (\epsilon^{1/2}-1)/(\epsilon^{1/2}+1) \qquad (2)$$

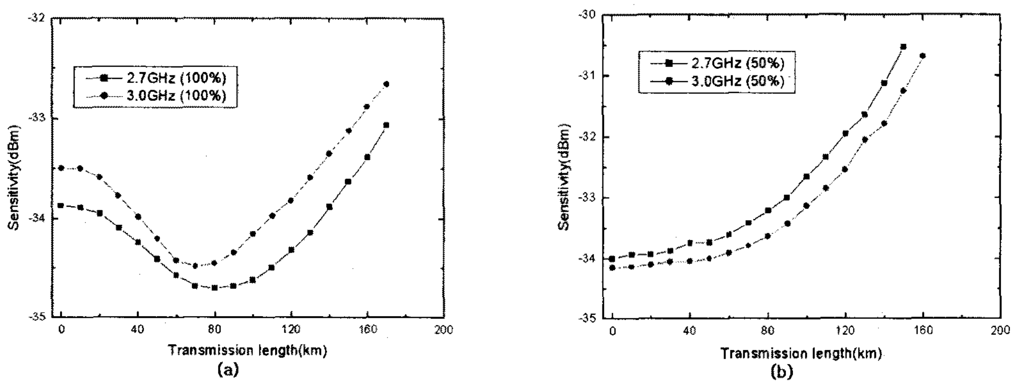
The asymmetry ratio of 1.3 corresponds to the residual chirp parameter $\alpha$ of −0.265 in our experiment. The residual chirp also could be compensated by the applied chirp that can be changed by the applied driving voltages between two electrodes[9].

The eye diagrams for $\gamma$=1.3 with 2.7[GHz] and 3.0[GHz] for 50[%] driving voltage ratios are shown in Fig. 5 (a) and 5 (b) respectively. For the broader bandwidth[Fig. 5 (b)], the increase in the amplitude jitters of marks is reduced and the suppression in the ripples of the spaces is increased with the reduced driving voltage ratios compared to the 100[%] driving voltage ratio [Fig. 4 (b)]. As a result, it widens the eye-opening. It means that under the asymmetry condition, reducing driving voltages and widening LPF bandwidths gives a chance to improve the extinction ratio.



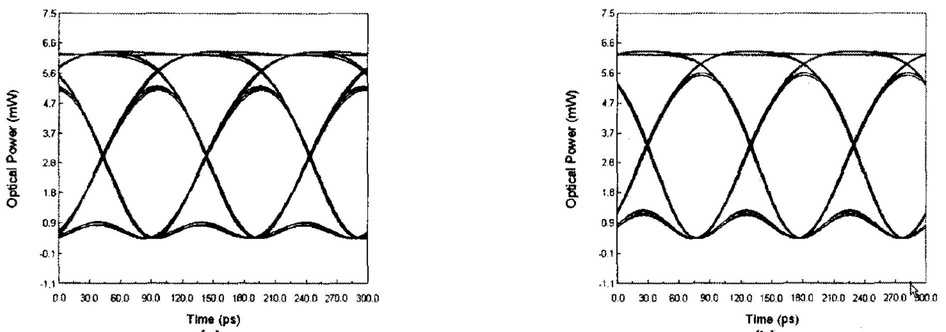

(a) (b)

Fig. 5. Eye diagrams at 0[km] based on $\gamma$=1.3 and 50[%] driving voltage ratio with the LPF bandwidth (a) 2.7[GHz] (b) 3.0[GHz]




(a) (b)

Fig. 6. Calculated receiver sensitivities at $10^{-9}$ BER with 2.7[GHz] and 3.0[GHz] LPF and $\gamma$=1.3 as a function of transmission distance for the driving voltage ratio (a) 100[%] (b) 50[%]




(a) (b)

Fig. 7. Eye diagrams at 0[km] based on $\gamma$=0.7 and 50[%] driving voltage ratio with the LPF bandwidth (a) 2.7[GHz] (b) 3.0[GHz]

Fig. 6 shows the receiver sensitivities (BER= $10^{-9}$) for a SSMF length of 200[km]. In case of the 50[%] driving voltage ratio, it is improved due to the wider LPF. On the contrary, the wider

LPF cause the receiver sensitivity to degrade in the 100[%] driving voltage ratio shown in Fig. 6 (a).

In case of $\gamma$= 0.7, The similar results to the case of $\gamma$=1.3 can be obtained in the eye diagrams and the receiver sensitivities shown in Fig. 7 and Fig. 8, respectively.

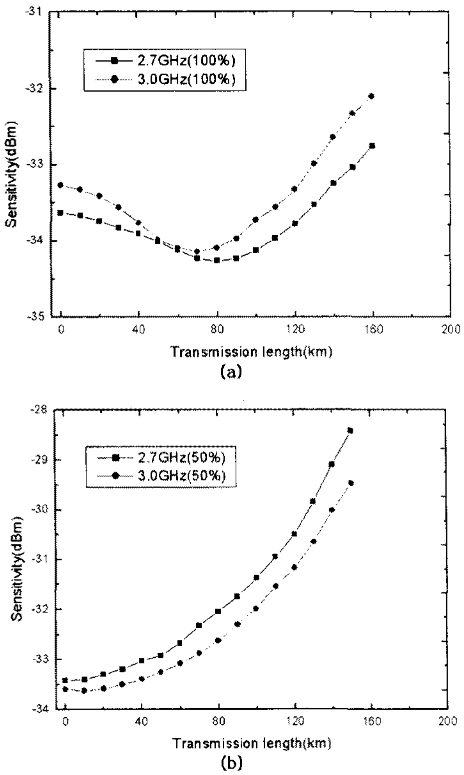



**Fig. 8. Calculated receiver sensitivities at $10^{-9}$ BER with 2.7[GHz] and 3.0[GHz] LPF and $\gamma$=0.7 as a function of transmission distance for the driving voltage ratio (a) 100[%] (b) 50[%]**

As a result, wider LPF can be applied to adjust the ripples and the eye-opening without significantly increasing the amplitude jitters and to improve the receiver sensitivities within lowering the driving voltage ratios under the non-ideal MZM condition.

Fig. 9 plots the receiver sensitivities as a function of the transmission distance and the 80[%], 50[%], 25[%] driving voltage ratios with $\gamma$ =1.3 based on the 2.7 and 3.0[GHz] LPF bandwidth, respectively. It is shown that the smaller driving voltage ratio is, the more sensitivity improves under the asymmetry condition. Nevertheless, the 80[%] driving voltage ratio with 3.0[GHz] bandwidth shows better dispersion tolerance than any other driving voltage ratios.

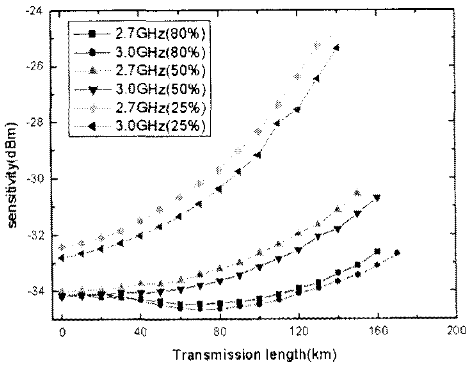



**Fig. 9. Comparison of calculated receiver sensitivities at $10^{-9}$ BER for 80[%], 50[%] and 25[%] driving voltage ratio with 2.7[GHz] and 3.0[GHz] LPF and $\gamma$=1.3 as a function of transmission distance**

## 4. CONCLUSION

We theoretically investigated the effect of the LPF bandwidths and driving voltage ratios under the asymmetry ratio $\gamma \neq 1$ that accompanies the residual chirp and the finite extinction ratios of MZ modulators. Lowering the driving voltage ratios below 100[%] which is related to the applied chirp can improve the receiver sensitivities with widening the LPF bandwidths even if the asymmetry ratio is not exactly 1. Especially, the driving voltage ratio 80[%] has better transmission performance than the driving voltage ratio 50[%]

and 25[%] cases. Accordingly, selecting the broader LPFs and lowering the driving voltage ratios exhibit better dispersion tolerance under the non-ideal MZM conditions.

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## Biography

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