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Impact of extinction ratio of single arm $\sin^2$ $LiNbO_3$ Mach–Zehnder modulator on the performance of 10 and 20 Gb/s NRZ optical communication system

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Abstract

We investigate the impact of extinction ratio of single arm $\sin^2$ $LiNbO_3$ Mach–Zehnder (MZ) amplitude modulator on the performance of 10 and 20 Gb/s single-channel optical communication system. For different fiber lengths, the system performance has been analyzed with the increase in the extinction ratio. The effect of variation in dispersion parameter has also been illustrated. The impact of extinction ratio (ζ), dispersion parameter and length of the fiber has been further optimized with minimum bit error rate (BER) at optimal decision threshold (10^{-9}) for 10 and 20 Gb/s bit rate. It is found that the system gives optimum performance at extinction ratio (ζ) value 20 dB. The increase in the transmission distance from 468 km for 10 Gb/s to 532 km for 20 Gb/s has been reported, and 8 dB improvement in the Q value has been observed as the value of ζ is increased from 10 to 20 dB. At 20 Gb/s, the system gives optimum performance for dispersion parameter value only up to 4 ps/nm km; however, at 10 Gb/s the system can operate for dispersion values up to 14.3 ps/nm km. Further we investigate the self-phase modulation (SPM) effect for the increase in the input power. It is observed that the SPM effect is negligible below 3 dB m input power and it increases at higher power levels.

Keywords: Extinction ratio; BER; SPM

1. Introduction

At bit rates of 10 Gb/s or higher, the frequency chirp imposed by the direct modulation method become large enough that direct modulation of semiconductor lasers is rarely used. For such high-speed optical transmitters, external modulators are preferred. In these systems, intensity modulated pulse is distorted by fiber dispersion, fiber nonlinearity and transient chirping of transmitters [1]. Therefore, in order to estimate transmission performance, transmitter characteristics as well as waveform distortion such as dispersion and nonlinear effects must be considered. The important parameters to be considered in a transmitter are the input power, bit rate and the characteristics of the modulator, i.e. chirp and the extinction ratio. Extinction ratio is an important parameter included in the specifications of the modulator, which describes the content strength of the signal that the transmitter puts on the fiber.

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Martin Pauer et al. [2,3] showed that the finite extinction ratios can significantly reduce the achievable RZ coding gain. They quantitatively discussed the influence of the optical pulse shape on the achievable RZ coding gain and especially when the RZ signals are produced by direct-modulation methods. They further proved that the RZ gain drops considerably as the extinction ratio (ζ) decreases and the requirements on extinction ratio (ζ) are more severe if lower duty cycle is employed. Yonglin et al. [4] reported that in addition to the X talk level, the extinction ratio can also be used to characterize the suitability of a switch for optical networking applications and that the mechanical switches have extinction ratios of 40–50 dB and high-speed external modulators tend to have X ratios of 10–25 dB.

The effect of frequency response of receiver and chirping of transmitter on transmission performance of 10 Gb/s NRZ $LiNbO_3$ modulator-based lightwave systems had been investigated by Sung Kee Kim et al. [5,6]. By solving the nonlinear Schrodinger wave equation including chirping for the transmitters, they evaluated transmission performance by bit error rate (BER) and eye opening penalty. They further investigated [10,11] cost-effective and simple duobinary modulations with/without using low pass filters for the conventional duobinary modulation and analyzed the effects of the electrical bandwidth and the DC extinction ratio of Mach–Zehnder (MZ) modulators for transmission performances of the 10 Gb/s system. In another paper, Jeohoon Lee et al. [7] experimentally and theoretically investigated the electrical eye margin characteristics as the method of performance evaluation and prediction of high-speed optical transmission systems for single-channel 10 Gb/s optical transmission systems including chirp and extinction ratio. They showed that negative chirp can reduce the group velocity dispersion (GVD) than the positive chirp. Lima et al. [12] reported numerical studies of the propagation of ultra-short optical soliton pulses in a four-stage MZ interferometer (4SMZI), which is constructed with ordinary telecommunication fiber and dispersion decreasing fibers. They showed that crosstalk (X talk) level is dependent on the pump power and the dispersion of the fibers. Joon-Hak et al. [13] presented a technique for improving the input power dynamic range and extinction ratio of wavelength converters based on cross-gain modulation in a semiconductor optical amplifier.

However, the impact of extinction ratio of the modulator with dispersion and self-phase modulation (SPM) effect for 10 and 20 Gb/s system is not available as such in the literature, and thus is explored here to investigate the performance of the single-channel optical communication system for varying length and dispersion values. The system performance has also been investigated for different input powers to analyze the SPM effect.

2. System description and simulation

The optical communication system shown in Fig. 1 has been numerically simulated to investigate the effect of extinction ratio of the MZ $LiNbO_3$ external modulator on the system performance using the split step Fourier transform method. Here, the issue of extinction ratio of the modulator is addressed from the transmission point of view for a 10 and 20 Gb/s NRZ optical communication system.

The system transmitter consists of the pseudo random data source having random generating polynomial of 7°, the rectangular NRZ driver with -2.5 V low level and 2.5 V high level and the low pass Bessel filter with 5 poles and -3 dB cutoff frequency = 8 GHz. The CW laser source is taken with variable power, center emission frequency = 193THz, noise bandwidth = ideal, line width FWHM = 10 MHz.

The amplitude modulator model considered here implements a single arm MZ amplitude modulator with $\sin^2$ electrical shaped input–output *P–V* characteristic based on the electro-optic effects in the $LiNbO_3$ devices. As given in Refs. [6,9], for the input optical signal V_{in} applied to the MZ modulator, the output electric field is given as

$$\vec{E}_{out} = 10^{-(EL_{dB}/20)}\left\{\cos\phi_D - j\frac{1}{\varsigma_{lin}}\sin\phi_D\right\}e^{j\varepsilon}\vec{E}_{in} \tag{1}$$

where $\vec{E}_{in}$ is the incoming electric field, EL_{dB} is the excess loss introduced by the modulator, phase difference ϕ_D is given as

$$\phi_D = \frac{\pi}{2}\left[\frac{V_{in} - V_{on}}{V_\pi}\right] \tag{2}$$

where V_π is the switching voltage of the modulator and V_{on} is the maximum transmissivity offset voltage, i.e. the value of the electrical input corresponding to the maximum transmission state. Here, $V_{on} = 2.5$ V and

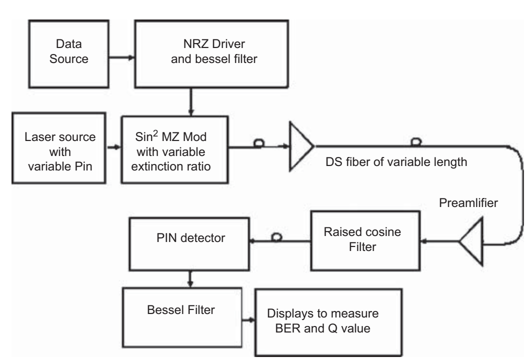

Fig. 1. Schematic of simulation setup to examine the performance of modulator with variable extinction ratio (10–20 dB) for varying fiber length (50–550 km).