Optik 125 (2014) 5037–5040

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Improving the performance of three level code division multiplexing using the optimization of signal level spacing

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ARTICLE INFO

Article history:
Received 17 July 2013
Accepted 9 January 2014

Keywords:
Optical communication
3LCDM
Dual drive mach zehnder
Multiplexing
Level spacing

ABSTRACT

In order to optimize the performance of three level code division multiplexing (3LCDM) at 2×20 Gb/s data rate, signal level spacing technique is investigated in this paper. The 3LCDM performance is improved considerably using both electrical and optical level spacing optimization configurations. The results demonstrate that by optimization, in conditions of the optical signal-to-noise ratio, an improvement of around 4.5 dB can be achieved in both approaches as well as 3.3 dB in the electrical configuration and 3.5 dB in the optical configuration can be accomplished for the 3LCDM in terms of the receiver sensitivity.

1. Introduction

Wavelength division multiplexing (WDM) offers huge profits to the optical fibre communication system. To improve the WDM transmission performance, various techniques have been proposed which include implementing the advanced dispersion management [1,2] and advanced modulation formats [3,4]. The modulation with compact spectrum and good dispersion tolerance make a perfect modulation design for long-haul WDM transmission links [5]. While the RZ and NRZ line coding are the most commonly used formats in high-speed communication systems, there is another multiplexing techniques namely three level code division multiplexing (3LCDM), initially reported in [6] taking advantages of both NRZ and RZ line coding to offer double capacity of WDM.

However, this technique faces a major problem due to its three-level properties especially when the optical amplifier is used in long distance system. Since the noise is intensity dependent, the signals having a higher power level experience more noise as compared to the signals having lower power level. This difference causes dissimilar performance for 3LCDM users and degrades the system's performance.

Thus in this study, two methods are employed to optimize the level spacing of the 3LCDM; while one method is in the electrical configuration and another one is the optical configuration.

2. Simulation set up

Fig. 1 illustrates the proposed simulation set up of the 3LCDM code for electrical configuration at the aggregate bit rate of 40 Gb/s in order to combat the degradation performance of the existing 3LCDM. At the transmitter side, each user transmits data (i.e. data 1 and data 2) with 20 Gb/s of bit rate at PRBS of 2^{10}-1. The system consists of one NRZ pulse generator and one RZ pulse generator. Both users have identical peak voltages at the input of multiplexer and both data are multiplexed through a power combiner, which adds up the amplitude of the input signals once they are synchronized together. The multiplexed signal will be then fed into the signal level spacing controller, modelled by a Matlab co-simulation component. The equation $y(t) = x^m(t)$ [7] is used to control the signal level spacing, where $x(t)$ is the signal having an identical level spacing output from the multiplexer and $y(t)$ is the output signal which is controlled by positive real number, m. The output signal has different level spacing between the lower and upper level and will be modulated onto the distributed feedback (DFB) laser with 10 MHz line width that operates at 1552.5 nm wavelength using a Mach Zehnder modulator. At the receiver side, the optical signal is detected by a PIN photodiode and passes through a low pass filter followed by a demultiplexer. The demultiplexer functions as a clock and the data recovery.

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http://dx.doi.org/10.1016/j.ijleo.2014.06.001
0030-4026/

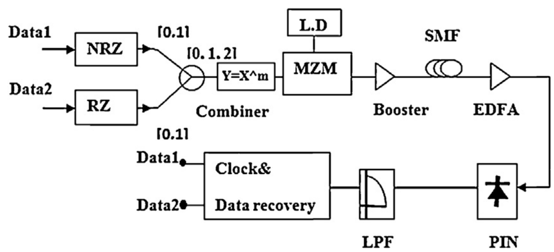

Fig. 1. Simulation set up for electrical configuration.

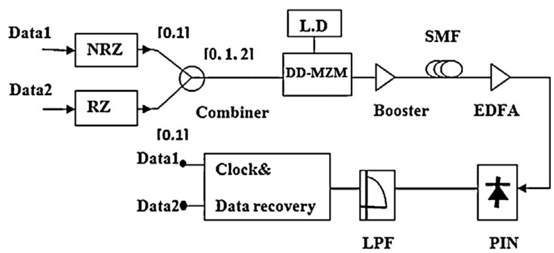

Fig. 2. Simulation set up for optical configuration.

Note that the maximum amplitude of the electrical signal from the electrical component is set to the amplitude similar to the peak power of the laser diode. The 3LCDM is tested using this method with different values of m. By sweeping the optical attenuator value, the system OSNR is obtained. Then, the OSNR value is measured after the pre-amplifier and before the photodiode by using a WDM analyzer.

This method can overcome the issue of non-uniform amplitude distribution between different levels in the multiplexed signal by stabilizing the power distribution among the 3LCDM channels. The electrical component coefficient can change the amplitude distribution. By using different values of m at the same bit rate, the best performance can be observed.

Fig. 2 exhibits the simulation set up for the optical configuration on the 3LCDM system. Dual-Drive Mach–Zehnder-Modulator (DD-MZM) is used in the 3LCDM setup at 40 Gb/s data rate to improve the performance of this system. The modulated signal (DD-MZM or IM) is transmitted over the transmission link that include a booster and the pre-amplifier which are based on the erbium doped fibre amplifier (EDFA) with 5 dB noise figure.

The dual-drive format has the advantage of reducing peak-to-peak modulation voltage. In this simulation, when the bias voltage is adjusted at the optimum setting for both ports, the sensitivity of the worst channel could be enhanced in 3LCDM. It is well agreed that the dual drive Mach–Zehnder modulators also play a role in light wave communication systems. In this regards, they are suitable as discrete modulators [8,9] as well as monolithically integrated laser modulators [10,11]. The fact is that the applied voltage has nonlinear functions owing to the quantum confined Stark effect. These functions entail the attenuation and phase constants of an optical signal which is broadcasted in the modulator waveguide. To this end, these constants along with the device structure are able to specify the extinction ratio as well as the chirp related to the modulated optical signal [12]. It needs to be asserted that for the purpose of gaining a proper quantity of negative chirp as well as earning a high extinction ratio and consequently boosting the transmission performance, a voluminous extent of research has been hitherto conducted so that the modulator waveguide's composition and structure will be enhanced. The phase-shift Mach–Zehnder modulator which had asymmetric Y-branch waveguides has been ultimately yielded by such surveys [13,14]. The point is that a phase shift of the radians occurs between the optical signals at the output Y-branch because of the differential length of half a wavelength which arises between the modulator's two arms. In case measuring the modulator properties implications on the system performance is intended to be done efficiently, there is a need for device models which are able to precisely determine both static and dynamic properties. Although the detailed models would boost our understanding of the device properties, they fail to aid us in surveys which are aimed at appraising the system design and performance due to the fact that they are normally too intricate and thorough computationally in this sense [15,16]. In the case the splitting ratio of the input and output Y-branches are identical, the output signal ($E(\upsilon_1,\upsilon_2)$) from a modulator is given by [17]:

$$E(V_1,V_2)=\frac{E_0}{1+S_r}S_r\times\exp\left(-\left(\frac{\Delta\alpha_a(V_1)}{2}+j\times\Delta\beta(V_1)L\right)\right)+\exp\left(-\left(\frac{\Delta\alpha_a(V_2)}{2}+j\times\Delta\beta(V_2)\emptyset_0\right)\right) \quad (1)$$

$$E(V_1,V_2)=\sqrt{I}(V_1,V_2)\times\exp(j\times\emptyset(V_1,V_2)) \quad (2)$$

where E_0 is the input optical signal to the modulator; $S_r=P_1/P_2$ is the Y-branch power splitting ratio; $0.5\Delta\alpha_a$ is the attenuation constant; $\Delta\beta$ is the phase constant; L is the interaction length of the modulator arm; $\emptyset_0$ is zero radians for a conventional modulator and π radian for a phase-shift modulator; V_1 and V_2 are the voltages applied to arms 1 and 2, respectively; I is the intensity of the optical signal; $\emptyset$ is the phase. The V_i (for $i=1, 2$) is defined as [17]:

$$V_{i(t)}=V_{bi}+V_{\text{mod}1,2}\upsilon(t) \quad (3)$$

where V_{bi} is the bias voltage; $V_{\text{mod}1,2}$ is the peak-to-peak modulation voltage of the input signal applied on arms 1 and 2; and $\upsilon(t)$ is the input modulation waveform with a peak to peak amplitude of one and average value of zero. Since voltage of the input modulating waveform ($\upsilon(t)$) is considered to be normalized, the model also utilized a dual-drive (push–pull) modulation, where $\Delta V_1=-\Delta V_2$.

In the simulation, the peak to peak magnitude of the input modulation waveform implemented on arms 1 and 2 of the modulator can be altered by $V_{\text{mod}1,2}$. In this study, $V_{\text{mod}1,2}$ of DD-MZM is fixed with $V_{b2}-V_{b1}$ in all the simulation where the V_{b2} and V_{b1} are the voltage of the modulating signal applied on arms 1 and 2. The level spacing is controlled by varying the DD-MZM parameters, including the bias voltages and V_{b2}, V_{b1}, as well as the splitting ratio (S_r). In this paper, the effect of V_{b2} on the 3LCDM system will be investigated. Firstly, $V_{b2}=-V_{b1}$ is considered and then, V_{b2} and V_{b1} are varied independently.

3. Results and discussions

In this section, a discussion is presented on the result of optimizing the 3LCDM performance through controlling signal level spacing improved using electrical and optical configurations.

Fig. 3 represents the results of BER versus the coefficient value of m in the electrical configuration for the 3LCDM system at fixed OSNR of 26 dB.

The BER of 2 × 20 Gb/ps 3LCDM is used as a function of the coefficient m used in the electrical configuration. From the graph, it can be concluded that at the smaller value of m (i.e. less than 1.5), the lower level performs better than the upper one. However, as the m increases (after 1.5), the performance of the lower level degrades while the upper one improves. At one point, both users have the same performance referring to the coefficient value. The graph illustrates that the system operates in the optimized state with the coefficient value $m=1.51$, where the two users have similar parallel BER.

Based on Fig. 2 for the optical configuration, the effect of the DD-MZM modulator splitting ratio is tested at fixed $V_{b1}=-2.8$ V