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Investigation of modulator chirp and extinction ratio in different RZ- and NRZ duobinary transmitter modules for performance optimization

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ABSTRACT

In this work we present a comparative investigation of modulator chirp and extinction ratio in different transmitter modules for 10 Gbps, 20 Gbps and 40 Gbps RZ- and NRZ duobinary transmission. For comparative analysis three types of transmission modules have been considered viz. push–pull configuration based on dual arm MZIM, delay-and-add circuit based single arm MZIM and a duobinary filter followed by single arm MZIM. For each case, the modulator chirp has been optimized with an extinction ratio of 20 dB. Investigation has been carried out to find extinction ratio of single arm MZIM used for RZ- and NRZ duobinary transmission that offers system performance comparable to dual arm MZIM at 10, 20 and 40 Gbps. The results help choosing the best suitable transmitter module with optimized modulator chirp and extinction ratio.

1. Introduction

In high speed optical communication systems duobinary modulation is an effective solution that provides a better spectral efficiency and reduces the performance degradation owing to dispersion and nonlinear effects [1–3]. In the 1980s and the early 1990s, direct modulation of semiconductor laser was the mostly used technique. However, direct modulation has several limiting factors like it induces unwanted chirps which results in spectral broadening of the signal, hence causing severe dispersion penalties [4]. Directly-modulated optical signals experience fluctuations in intensity due to Relative Intensity Noise (RIN) of the semiconductor laser. Nonzero linewidth of laser sources introduces laser phase noise thus for high speed transmission direct modulation is usually not preferred. Hence, external modulation has been an essential choice for the high speed long-haul communication [5,6].

External modulators remove the large amount of wavelength chirping which will otherwise be included if laser diode is directly modulated. Mainly two types of semiconductor external modulators are available viz. Electro-Optic Modulator (EOM) and Electro-Absorption Modulators (EAM) [6]. Of these two modulators, EOM that changes the band gap energy with applied electric field is mostly preferred because of various advantages like linear response characteristic, high extinction ratio, ability to control phase, frequency or amplitude of the light wave carrier owing to the properties of electro optic material. Even for very low value of driving voltage EOM is able to achieve high speed modulation [7,8].

2. Theory

In optical domain, data modulation is achieved using two types of modulators: optical phase modulator and optical intensity modulator. An Electro-Optic Phase Modulator (EOPM) uses only one electrode. When a driving voltage is applied to the electrode, the refractive index of the electro-optic waveguide changes accordingly, thus slowing down the light wave and hence inducing a delay on the optical signal. The induced delay corresponds to the phase change, thus an EOPM is able to manipulate the phase of the light wave carrier [9].

$$\Phi(t)=\frac{\pi(V(t)+\ V_{\text{bias}})}{V_{\pi}} \tag{1}$$

where V_{π} is the driving voltage required to create a π phase shift, $V(t)$ is a time-varying driving signal voltage and V_{bias} is dc bias voltage.

Optical field E_o at the output of the EOPM is given as:

$$E_o(t)=E_i(t)e^{j\varphi(t)} \tag{2}$$

Optical intensity modulator uses two EOPMs in a parallel structure to form a Mach–Zehnder interferometer commonly known as the Mach–Zehnder intensity modulator (MZIM) [9]. Input optical signal splits equally in the two arms of the MZIM which are actually EOPMs for modulating the phase of the optical carrier. At the output, the two arms are coupled either constructively or destructively to provide intensity modulated optical pulses.

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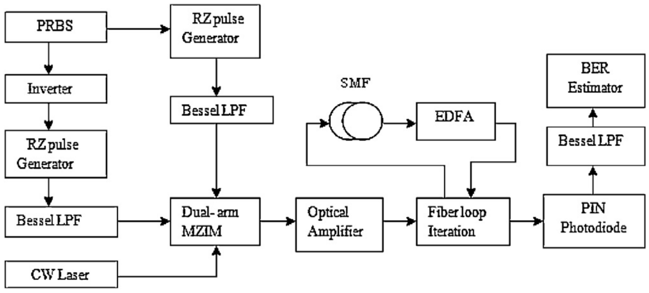

Fig. 1. Duobinary transmitter module with dual-arm MZIM (T#1).

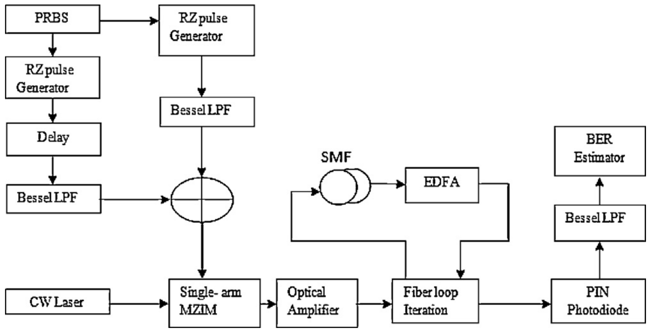

Fig. 2. Duobinary transmitter with single-arm MZIM delay-and-add circuit (T#2).

MZIM can be of two types: single-arm MZIM and dual-arm MZIM. In single-arm MZIM only one single driving voltage is applied to the either arm of MZIM [9] and the output transmitted optical field $E_o(t)$ is given as

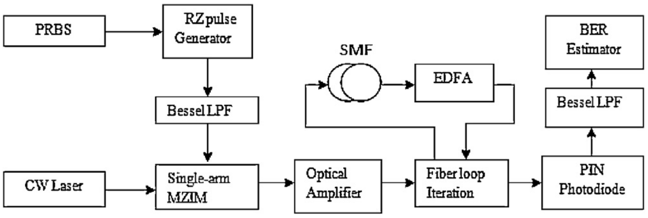

Fig. 3. Duobinary transmitter with single-arm transmitter and filter circuit (T#3).

$$\begin{aligned} E_o(t) &= \frac{E_i(t)}{2}\left[1+e^{j\pi(V(t)+V_{\text{bias}})/V_\pi}\right] \\ &= E_i\cos\left[\frac{\pi(V(t)+V_{\text{bias}})}{2V\pi}\right]e^{j[\pi/2(V(t)+V_{\text{bias}})/V_\pi]} \end{aligned} \tag{3}$$

Existence of the phase term in Eq. (3) shows that the chirping effect is present, thus we can say that the single-arm MZIM generated signals are not chirp-free. Particular structure of the MZIM can only minimize the chirping (x-cut MZIM). It has been found that a small amount of chirp is useful for transmission [9]. Dual-arm MZIM has push–pull arrangement where the dual drive voltages $V_1(t)$ and $V_2(t)$ are inverse to each other and thus, able to completely eliminate the chirping effect in the modulation. The transmitted optical field can be written as:

$$\begin{aligned} E_o(t) &= \frac{E_i(t)}{2}\left[e^{j\pi(V(t)+V_{\text{bias}})/V_\pi}+e^{j\pi-(V(t)+V_{\text{bias}})/V_\pi}\right] \\ &= E_i\cos\left[\frac{\pi(V(t)+V_{\text{bias}})}{2V\pi}\right] \end{aligned} \tag{4}$$

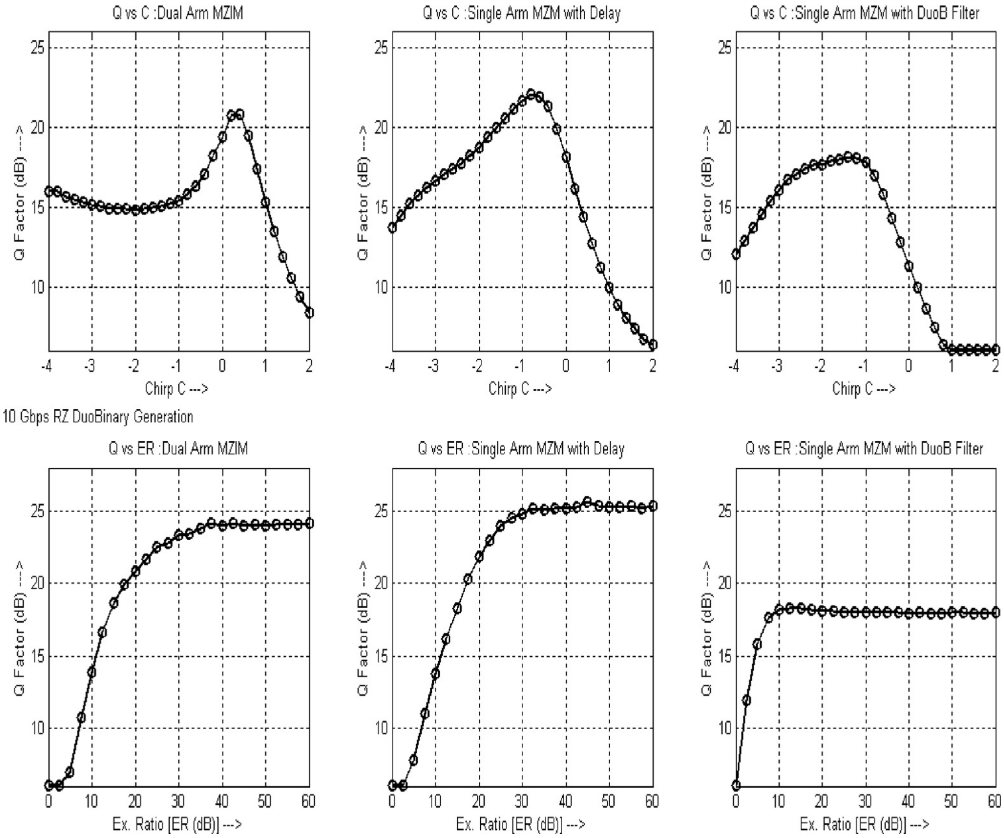

Fig. 4. Comparison of 10 Gbps RZ duobinary transmitter modules.