Chirped duobinary transmission (CDBT) for mitigating the self-phase modulation limiting effect

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Abstract: We present a new modulation format called chirped duobinary transmission (CDBT). The dispersion limited transmission distance of conventional chirp-free duobinary transmission is enlarged significantly, especially in the nonlinear regime by interaction of SPM and chirp.

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1. Introduction

It is well known, that optical duobinary transmission increases the bandwidth efficiency, broadens the dispersion limited transmission distance, increases the dispersion tolerance and suppresses stimulated Brillouin scattering [1-3]. Duobinary transmission (DBT) has been investigated mainly in the linear regime of the fiber channel, and its improvement has been shown. However in the nonlinear regime with self-phase modulation (SPM), the improvement in dispersion tolerance of DBT decreases rapidly due to the SPM limit [4].

Up to now duobinary signals are generated by a Mach-Zehnder modulator (MZM) driven in push-pull configuration to ensure a chirp-free optical duobinary signal. Residual chirp of the Mach-Zehnder modulator decreases the performance of the duobinary transmission since the chirp polarity alternates [5].

The improved transmission performance of binary signals with negative pre-chirp in case of anomal dispersion ($D > 0$) is well known. In contrast positive chirping of binary signals decreases the transmission performance [6]. The self-phase modulation (SPM) effect increases the performance of chirped binary transmission, for negative as well as for positive chirped signals [7].

In this paper for the first time we present a method to generate an either positive or negative chirped duobinary transmission (CDBT) signal. We investigate the performance of chirped duobinary transmission and the combined influence of the SPM effect and chirp and compare it to conventional chirp-free duobinary transmission.

2. Principle of the chirped duobinary transmission (CDBT)

A chirped duobinary signal is generated by modulating the phase of a chirp-free duobinary signal proportional to the binary NRZ data d(t) resulting in the phase signal $\varphi(t) \sim \pm\Delta\Phi\, d(t)$. Magnitude $\Delta\Phi$ and sign of the chirp is controlled by an amplifier at the input of the phase modulator. Thus, we can generate a duobinary signal with either positive or negative chirp.

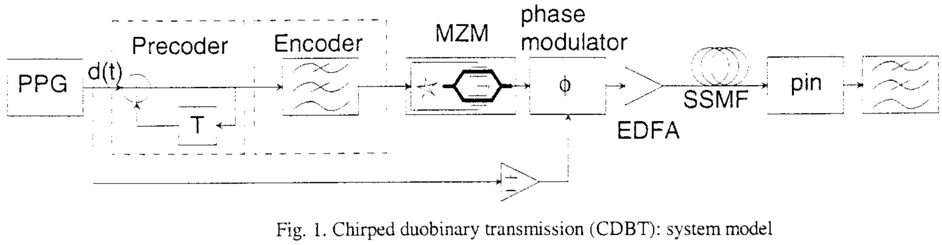

Fig. 1. Chirped duobinary transmission (CDBT): system model

The transmitter of our system model (fig. 1) consists of a 10Gb/s pulse pattern generator (PPG), a duobinary encoder with precoding and a dual drive MZM to generate chirp-free duobinary signals. The chirp is induced by an additional phase modulator driven by the data signal. We transmit over standard single mode fiber (SSMF, dispersion $D = 17$ ps/nm/km, nonlinear coefficient $\gamma = 1{,}62\ (\mathrm{W}\cdot\mathrm{km})^{-1}$) with variable length and optical input power. The receiver consists of a pin diode followed by a 2^{nd} order Butterworth lowpass filter with 7GHz cut-off frequency.

3. Simulation results

We compare the performance of chirp-free and chirped duobinary transmission by calculating the Q-factor on the basis of an optical signal-to-noise ratio of 25 dB measured in 0.1 nm bandwidth. Fig. 2 (a) shows the Q-factor related to the fiber length in the linear and nonlinear (optical input power: 15dBm) regime. For CDBT in each configuration we choose the optimum value for $\Delta\Phi$, which is shown in fig. 2 (b). Considering the linear regime, we find that for short transmission distances the well-known penalty of DBT is reduced by adding negative chirp. For long distances there is only a slight improvement and the optimum chirp becomes positive. However in the nonlinear regime the performance of CDBT improves significantly above 100 km transmission distance compared to conventional chirp-free DBT, where SPM leads to a significant reduction in transmission length. Thus, CDBT may overcome the SPM limit of duobinary transmission [4]. The optimum phase shift increases with increasing fiber length and optical input power.

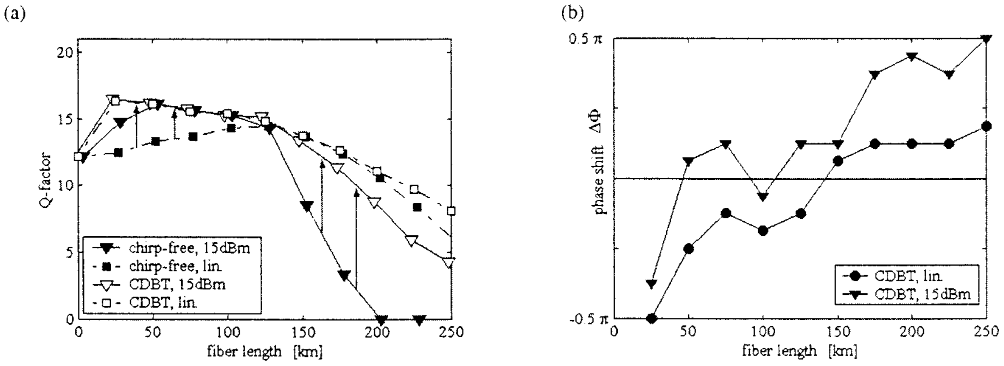

Fig. 2. Q-factor related to fiber length for optimized chirped duobinary transmission and chirp-free duobinary transmission in the linear and the nonlinear regime 15 dBm (a) and optimized phase shift $\Delta\Phi$ of CDBT (b)

Assuming a quality criterion of Q>10, CDBT enlarges the transmission distance up to 130% of the DBT distance in the nonlinear regime. The improved performance of chirped duobinary transmission is shown by comparing the eye diagrams of chirp-free and chirped duobinary transmission after 175 km SSMF in the nonlinear regime at 15 dBm (fig. 3). The eye diagram of CDBT is clearly open and less distorted.

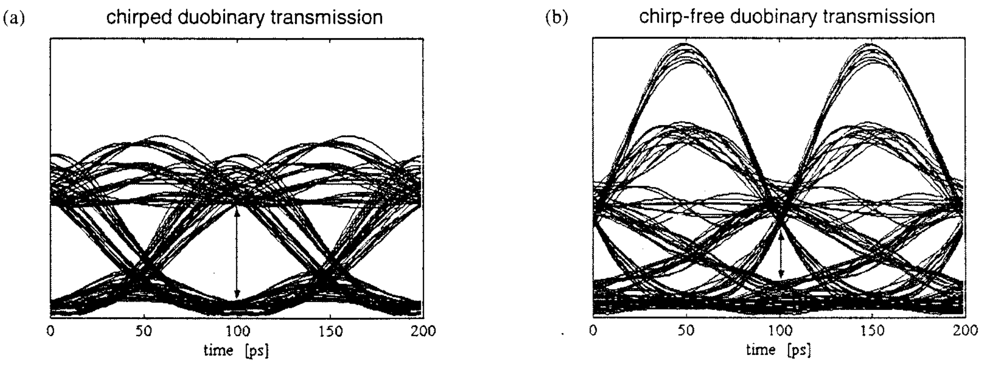

Fig. 3. Eye diagram of chirped duobinary transmission (a) and chirp-free duobinary transmission (b) after 175 km standard single mode fiber in the nonlinear regime (15 dBm)

4. Discussion

It is well known, that properly adjusted negative pre-chirp can cancel out pulse spreading due to chromatic dispersion [7], whereas positive pre-chirp results in increased pulse spreading. Considering binary transmission, pulse spreading of two pulses, that represent the "worst case" bit sequence "1 0 1", causes raising of the zero level resulting in a reduced eye opening. Therefore pulse compression results in improvement with binary transmission.

The SPM effect results in pulse compression provided the optical input power and fiber length are adjusted properly. However for strong SPM influence (high optical input power) the received signal may be distorted severely [4, 8].

Duobinary signalling prevents the "1 0 1" sequence by coding it into "1 0 -1". Therefore the rising of the zero level due to pulse spreading is prevented by interference between two pulses with opposite amplitude [9]. Thus duobinary transmission is less sensitive to pulse spreading.

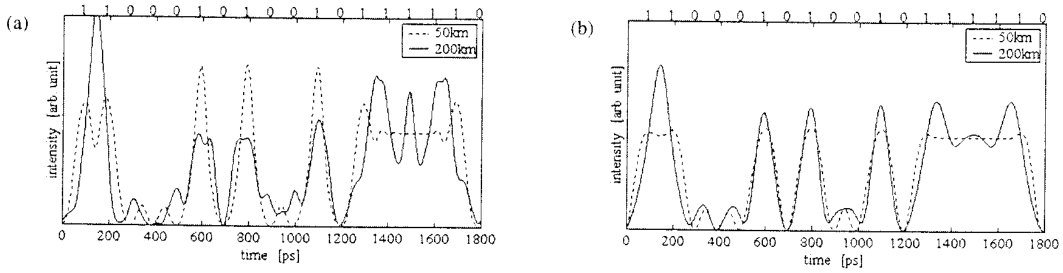

Fig.4. negative pre-chirped ($\Delta\Phi$ = -0.25π) duobinary signal (a) and chirp-free duobinary signal (b) after 50 km (dashed) and 200 km (solid) fiber length and pin diode

The influence of negative pre-chirping ($\Delta\Phi$ = -0.25π) on the duobinary signal in the linear regime is shown in fig. 4 (a). This phase shift is the optimum value for a fiber length of 50 km. The pulse compression caused by pre-chirp after 50 km results in an increased the Q-factor (see fig. 2 (a)). For comparison the shape of the chirp-free signal is shown in fig. 4 (b).

The deformation of the chirped signal after 200 km is much more significant in contrast to chirp-free DBT, because $\Delta\Phi$ = -0.25π is far beyond optimum for this length. The performance of CDBT can be optimized by increasing the phase shift with increasing fiber length. Considering the nonlinear regime, the optimized phase shift value is larger than in the linear regime. The optimum value of phase shift depends on the pre-chirp, chromatic dispersion and SPM. Positive pre-chirp offsets the SPM effect. Therefore CDBT overcomes the chromatic dispersion limit of chirp-free duobinary transmission.

5. Conclusion

We have presented a new modulation format called chirped duobinary transmission (CDBT). The performance of CDBT has been investigated in the linear and nonlinear regime. CDBT increases the performance significantly and broadens the transmission distance of duobinary signals especially in the nonlinear regime. An explanation of the improvement has been given in the time domain.

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