Impact of Self-Phase Modulation on Bandwidth Efficient Modulation Formats

T. Wuth, W. Kaiser and W. Rosenkranz
Chair for Communications, Christian-Albrechts-University of Kiel, Kaiserstraße 2, 24143 Kiel, Germany
tw@tf.uni-kiel.de

Abstract: We present the influence of self-phase modulation on duobinary and single sideband modulation. Additionally we determine and compare the receiver sensitivity for a bit error ratio of 10^{-9} varying fiber length and input power.

OCIS codes: (060.4510) Optical communications, (0600.4080) Modulation

1. Introduction

Standard single mode fiber (SSMF) with a zero dispersion wavelength at 1310 nm is the customary fiber in optical communication networks. The most related nonlinear effect for optical transmission is self-phase modulation (SPM), which distorts the transmitted signal and limits the launched optical input power into the fiber. However, this effect can be used to increase the transmission distance for binary modulation [1,2], if SPM-supported transmission is used. At high power levels precautions have to be taken with respect to the Stimulated Brillouin Scattering (SBS) threshold [3].

Duobinary optical transmission is an effective method to increase the dispersion tolerance and transmission length, caused by approximately halving the bandwidth of binary modulation [4,7]. Furthermore, no precautions must be taken to handle the SBS threshold up to an input power of 23.9 dBm [5,6]. So this kind of linecoding is well suitable for launching optical signals with high optical power.

A second kind of modulation format to obtain an optical signal with reduced bandwidth is single sideband (SSB) modulation. This modulation scheme will increase the dispersion tolerance and transmission length, caused by the reduced bandwidth spectrum, too [8]. To our knowledge, up to now the influence of nonlinear effects on SSB modulation has not been investigated. The SBS-effect occurs with this modulation format, so measures have to be take to avoid the SBS.

In this paper we investigate by simulation and experimentally the influence of SPM on duobinary and single sideband transmission and compare it to binary transmission

2. Experimental and Simulation Setup

A schematic of the experimental setup is shown in Fig. 1a. The pulse pattern generator (PPG) drives the 10 Gb/s transmitter (Tx), which is capable of generating binary, duobinary and single sideband signals. The transmitter is a DFB-Laser externally modulated by a $LiNbO_3$ Mach-Zehnder modulator and an additional phase modulator in the case of single sideband modulation. The optical signal is amplified with an erbium-doped fiber amplifier (EDFA) and the launched power level is controlled by a variable optical attenuator (VOA.). After transmission through the standard single mode fiber (SSMF) the signal is detected by a Receiver (Rx). The Receiver consists of an optical preamplifier, an optical/electrical converter and a clock recovery. A variable optical attenuator is inserted in front of the preamplifier in order to measure the receiver sensitivity.

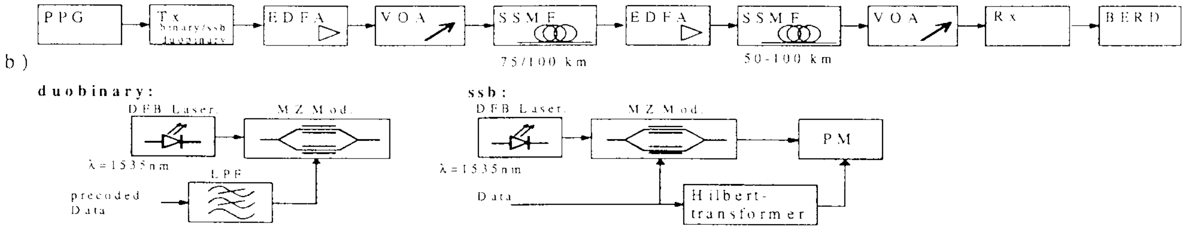

Fig. 1: a) Experimental Setup, b) duobinary and single sideband transmitter configuration

The transmitter for generating the duobinary and single sideband signal is shown in Fig. 1b. To obtain a duobinary signal the precoded data signal is filtered by a 2.6GHz Gaussian lowpass filter followed by a Mach-Zehnder modulator (Fig. 1b left). For getting an optical single sideband signal in a second step the intensity modulated signal (using a single arm Mach-Zehnder modulator) is phase modulated with the Hilbert transformed signal of the data signal, using a dual arm Mach-Zehnder modulator with equal input signals (Fig. 1b right)[8].

The fiber input power is varied from 0 dBm to 17dBm controlled by a variable optical attenuator. The length of the standard single mode fiber, was chosen for each modulation format according to the different dispersion limits. It ranges for binary modulation from 75 km to 100 km, for the duobinary and SSB modulation from 100 km to 200 km. For transmission lengths larger than 100 km the signal is amplified by another EDFA after 100 km to a level of 0 dBm. In order to overcome the SBS threshold it is necessary to broaden the spectrum of the launched optical signal by slowly varying frequency modulation.

The bit pattern used is a 2^{15}-1 pseudo-random binary sequence (PRBS).

The simulation setup is equivalent to the experimental setup described above

3. Results and discussion

We measure the necessary receiver input power to reach a constant BER of 10^{-9}. The results of the measurements are shown in Figure 2.

Binary:

In the case of binary transmission the well known effect of self-phase modulation is clearly observable (Fig. 2a). Due to SPM the receiver sensitivity is improved by 3.8dB (100 km transmission length) at a fiber input power of 11 dBm. If more than 11 dBm is launched into the fiber the necessary receiver input power grows rapidly.

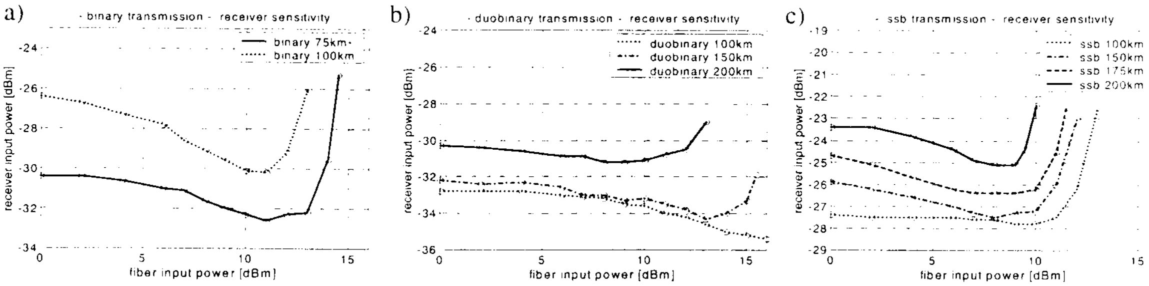

Fig. 2: Measured receiver sensitivity. a) binary transmission, b) duobinary transmission, c) ssb transmission

Duobinary:

In the case of duobinary transmission the effect of SPM is not as dominant as in the case of binary modulation (Fig. 2b). The gain which can be reached as a result of self-phase modulation is only about 0.8 dB, in the case of 200km transmission (2 dB by transmitting 150km). When the fiber input power exceeds 9 dBm, in the case of transmission distance of 200km (13dBm for 150km), the necessary receiver input power grows. In the case of 100 km duobinary transmission no deterioration of the receiver sensitivity can be observed.

Single sideband:

As in the case of duobinary transmission an unrepeatered distance of 200km uncompensated SSMF can be bridged. An improvement of the receiver sensitivity (1.7 dB in the case of 200km transmission and 9dBm fiber input power) can be observed at all fiber length (Fig. 2c). At fiber length of 100km the lowest receiver sensitivity improvement is observable. At 8dBm and at fiber length of 150km and 175km the maximum receiver sensitivity improvement is 1.6dB.

Simulation:

In our simulations of the transmission system we use the Q-factor and the eye open penalty as a quality criterion. We calculated the Q-Factor on the basis of an optical signal to noise ratio of 25dB measured in 0.1nm bandwidth. Simulation (Fig. 3) and measurement show good qualitative agreement, even though another quality criterion is used.

Fig. 4 shows some measured eye diagrams at 0 dBm and optimum fiber input powers for the maximum transmission length. The results of the experiments and simulations are qualitatively confirmed by inspection of the eye openings.

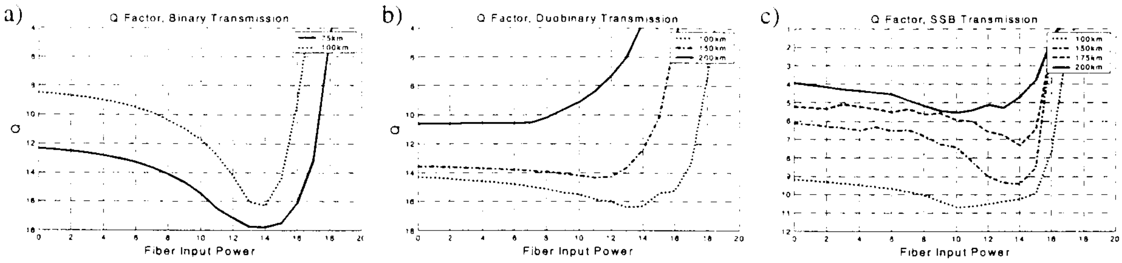

Fig. 3: Simulated Q-Factor. a) binary transmission, b) Duobinary transmission, c) single sideband transmission

Discussion:

The required receiver input power to transmit 200 km duobinary modulated data with a BER of 10^{-9} is comparable with the receiver input power of binary transmission over only 75 km. In the case of SSB modulation the necessary receiver input power for transmitting 150km is in the same magnitude as for transmitting binary signals over 100km SSMF. For SSB transmission in comparison to duobinary transmission the necessary receiver input power is higher for transmission distances beyond the capability of the binary modulation format. The reason for this is the worse back-to-back extinction. The SSB extinction is about 4.9dB, due to the linear excitation of the Mach-Zehnder modulator. The extinction of the duobinary signal is 10.4dB.

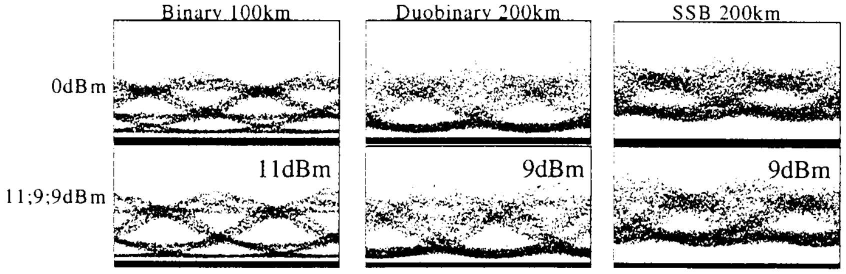

Fig. 4: Measured eye diagrams. From left to rigth: binary 100km at 0 and 11dBm; duobinary 200km at 0 and 9dBm; SSB 200km at 0 and 9dBm

4. Conclusion

We investigate the impact of SPM on duobinary and single sideband modulation. The effect of receiver sensitivity improvement can be observed independently of the modulation format. The intensity of the SPM effect (receiver sensitivity improvement) for a certain input power depends on the fiber length. Duobinary and SSB modulation shows approximately the same improved bandwidth efficiency. Also the uncompensated transmission length is enlarged compared to conventional binary transmission to at least 200km. With the results of this paper future WDM systems can be designed to exploit the receiver sensitivity improvement caused by SPM.

5. Acknowledgment

The authors wish to thank the Siemens AG Munich for valuable support with laboratory equipment.

6. References

[1] Govind P. Agrawal, *Nonlinear Fiber Optics*, Second Edition (Academic Press, San Diego, 1995).

[2] S. Bigo, D. Pennickx, M.W. Chbat, "Investigation of self-phase modulation limitation on 10 Gbit/s transmission over different types of fiber", OFC'98; 389-390 (1998)

[3] L. Eskildsen, P.B. Hansen, U. Koren, B.I. Miller, M.G. Young and K.F. Dreyer, "Stimulated Brillouin scattering suppression with low residual AM using a novel temperature wavelength-dithered DFB laser diode", Electronics Letters, **32**, 1387-1389 (1996).

[4] K. Yonenaga, S. Kuwano, "Dispersion-Tolerant Optical Transmission System Using Duobinary Transmitter and Binary Receiver", Journal of Lightwave Technology, **15**,. 1530-1537 (1997)

[5] T. Franck, T. Nørskov and A. Stentz,"Experimental verification of SBS suppresion by duobinary modulation", IOOC/ECOC 1997, Edinburgh

[6] K. Yonenaga, S. Kuwano, S. Norimatsu and N. Shibata, "Optical duobinary transmission system with no receiver sensitivity degradation", Electronics Letters, **31**, 302-304 (1995)

[7] W. Kaiser, M. Wichers, T. Wuth, W. Rosenkranz, C. Scheerer, C. Glingener, A. Färbert, J.-P. Elbers and G. Fischer, "SPM Limit of duobinary transmission", ECOC 2000, Munich (Germany), We. 7.2.2 (2000)

[8] M. Sieben, J. Conradi, D. Doods, B. Davies and S. Walklin, "10Gbit/s optical single sideband system", Electronics Letters, **33**, 971-973 (1997)