Upgrading of \textit{Nx40Gb/s} WDM System from 100GHz to 50GHz Channel Spacing by Duobinary Interleaving Concept with Optical Transversal Filter

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Abstract: We suggest the use of an optical transversal filter for simultaneously duobinary encoding of several WDM channels. An add-on concept to upgrade an existing 40Gb/s WDM system and reduce the channel spacing from 100 to 50GHz is proposed and investigated.

Introduction

Concepts that allow easy upgrading of existing WDM systems towards a higher spectral efficiency are needed to increase the overall transmission rate /1/. Duobinary encoding is one promising, bandwidth efficient modulation format with approximately half of the bandwidth compared to conventional on-off keying. Up to now, the encoding takes place in the electrical domain so that each WDM channel has to be encoded separately /2/. Using the periodic frequency response of an optical transversal filter (OTF) several channels can be encoded simultaneously. We will present a concept of upgrading an existing 40Gb/s WDM transmitter with 100GHz channel spacing into a duobinary transmitter with 50GHz channel spacing by means of two OTFs. The performance of both, the conventional binary transmitter and the duobinary transmitter with just half of the channel spacing, is investigated and compared in a single span system with post compensation.

Setup

The system under consideration, displayed in figure 1, consists of either a binary or a duobinary NRZ transmitter, a booster amplifier, 80 km of standard single mode fiber (\(\lambda = 1.55 \text{nm} \), \(\varphi = 6.5 \text{GHz} \cdot \text{km}^{-1}\)), a dispersion compensator and an optically preamplified receiver with an electrical Butterworth lowpass filter of 2nd order and 28GHz bandwidth. The input power of each channel is varied to investigate the influence of self phase modulation (SPM), cross phase modulation (XPM) and four wave mixing (FWM) on both transmitters with different channel spacings. Further on, at a fixed input power of 9dBm per channel, the residual dispersion is varied to investigate the dispersion tolerance of both transmitters.

The transmitter setup is as follows. Binary transmitter: Eight 40Gb/s channels with carrier frequencies at 193.0, 193.1, 193.2 GHz (conform to ITU-T G.692) are multiplexed to one WDM signal. Duobinary transmitter: As displayed in figure 2, there are two sets of four 40Gb/s channels with center frequencies at 193.0, 193.1, 193.3, 193.4GHz and 193.05, 193.15, 193.25, 193.35GHz (ITU-T G.692) respectively. Both sets are multiplexed separately into two WDM signals each consisting of four 40Gb/s channels with 100GHz channel spacing. All four 40Gb/s channels of each set are simultaneously duobinary encoded with just one OTF. By means of this, the spectrum of every channel is roughly divided by two, which allows to combine both sets with a 3dB coupler to a resulting WDM system with a 50GHz channel grid.

Figure 2: Duobinary Interleave WDM Transmitter

The OTF is of 4th order and has a flat spectral range (1SR) of 100GHz, corresponding to a tap delay of 10ps. The coefficients \((b_0 = 0.33, b_1 = 0.79, b_2 = 1, b_3 = 0.79, b_4 = 0.33)\) are chosen in a way that the frequency response approximates a linear phase bandpass with two-sided bandwidth of \(2.3\) of the bitrate and a cosine shaped main lobe, thus producing a duobinary signal. The setups for duobinary encoding with conventional electrical lowpass filter and the proposed optical bandpass filter are shown in figure 3.

(a) encoding with electrical lowpass

(b) encoding with optical bandpass

Figure 3: (a) Electrical (b) Optical Duobinary Encoding

Results

In figure 5 to 7, we show simulation results that are discussed in the following section. The simulations are based on the solution of the nonlinear Schrödinger equation
by the split-step method including FWM and XPM. In figure 5, we measure the eye opening penalty (EOP) normalized to the back-to-back case as a function of the optical input power per channel $P_{in}$. We select the channel with center frequency of 193.211Hz for binary and duobinary.

![Figure 5: Influence of Fiber Input Power](image)

The eye diagrams of the binary signal and the optically encoded duobinary signal at 193.211Hz and at 6dBm input power are shown in figure 6.

![Figure 6: (a) Binary 100GHz (b) Duobinary 50GHz at ch: 193.211Hz, 80km SSMF, 6dBm](image)

The dispersion tolerance of the binary and duobinary signal at 193.211Hz is investigated at a fiber input power per channel of 6dBm. The results are shown in figure 7.

![Figure 7: Dispersion Tolerance @ 6dBm](image)

**Discussion**

It is well known, that by means of duobinary encoding the spectral occupancy is roughly devided by 4. This allows to apply the duobinary interleaving concept to reduce the channel spacing of an existing $24$ to $50$GHz. In a single channel considerations were made that the bandwidth efficiency of duobinary decreases in presence of increasing nonlinear effects such as SPM. In this setup, we also have to consider interchannel nonlinear effects such as FWM and XPM that play an important role in systems with small channel spacing and high input power. These effects, cause additional frequency components that broaden the spectrum of each WDM signal. This is more crucial for the resulting WDM system with $50$GHz spacing than for the existing WDM system with $100$GHz spacing. Nevertheless, our results (see figure 5) show that it is possible to transmit duobinary encoded 40Gb/s WDM signals with 50GHz spacing when the fiber input power per channel is kept below 6dBm. The eye diagrams of figure 6 prove that the performance of the duobinary WDM system is only slightly worse than that of the binary WDM system even though the channel spacing is reduced from 100 to 50GHz. Figure 7 shows the superior dispersion tolerance of the duobinary setup with 50GHz spacing compared to the binary setup with 100GHz spacing even at an input power of 6dBm.

Besides these WDM considerations, there are also other advantages when the encoding is done in the optical domain. The symmetrical back-to-back eye diagram that occurs in case of using the optical duobinary bandpass filter results in a better back-to-back receiver sensitivity compared to the asymmetrical eye diagram produced by the electrical duobinary lowpass filter. Moreover, the difficulties in providing two identical signals at the two arms of the Mach-Zehnder modulator after electrical lowpass filtering are avoided. There is also no spectral broadening, when the encoding is implemenetd behind the Mach-Zehnder that has a nonlinear characteristic.

**Conclusion**

In our knowledge, duobinary encoding of several channels with one optical transversal filter is a completely new approach. Duobinary encoding with an OFT avoids fundamental problems that occur when electrical lowpass filters are used for duobinary encoding. We showed that just two OFTs and one 3dB coupler are necessary to merge two binary WDM systems with a channel spacing of 100GHz to one duobinary WDM system with 50 GHz channel spacing. No additional effort at the receiver is necessary when a differential predecoder is used at the transmitter. We demonstrated a good performance of this DWDM duobinary system with a spectral efficiency of 0.98bit/s/Hz within a single span setup for fiber input powers per channel of up to 6dBm. This means, we found an add-on concept that allows easy upgrading of an existing WDM system to double the total transmission rate.

**References**

1. S. Bigo et al., 10.27bit/s 256x42.7Gb/s PDM WDM transmission over 100km TECAD LiOH fiber with 1.28bit/s/Hz spectral efficiency, OFC, 2001, PD25-1