# Upgrading of *N*x40Gb/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 transveral 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, 80km of standard single mode fiber ($D=17$ps/nm·km, $\gamma=1.62(\mathrm{W\cdot km})^{-1}$), a dispersion compensator and an optically preamplified receiver with an electrical Butterworth lowpass filter of 2[nd] 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 6dBm per channel, the residual dispersion is varied to investigate the dispersion tolerance of both transmitters.

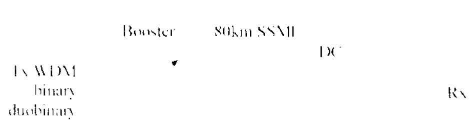


**Figure 1: WDM Single Span System**

The transmitter setup is as follows. Binary transmitter: Eight 40Gb/s channels with carrier frequencies at 193.0,193.1,...,193.7THz (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, 193.4THz and 193.05, 193.15, 193.25, 193.35THz (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.

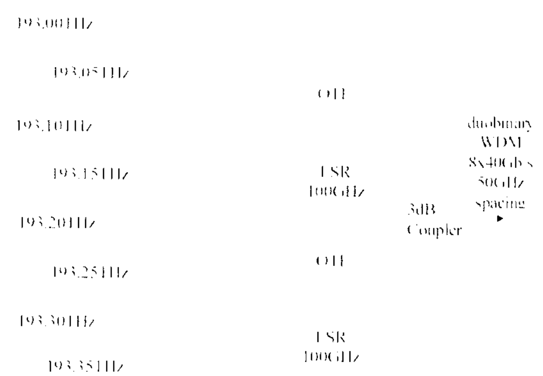


**Figure 2: Duobinary Interleave WDM Transmitter**

The OTF /3/ is of 4[th] order and has a free spectral range (FSR) of 100GHz, corresponding to a tap delay of 10ps. The coefficients ($h_0=0.33$, $h_1=0.79$, $h_2=1$, $h_3=0.79$, $h_4=0.33$) are chosen in a way that the frequency response approximates a linear phase bandpass with a two-sided bandwidth of 2/3 of the bitrate and a cosine shaped main lope, 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.

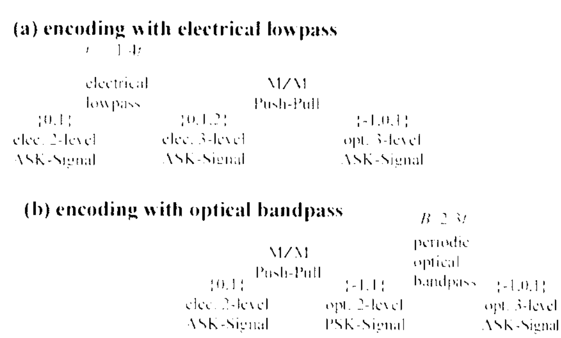


**Figure 3: (a) Electrical (b) Optical Duobinary Encoding**

## 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 193.2THz for binary and duobinary.

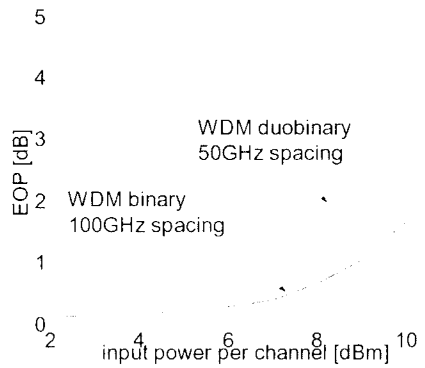


**Figure 5: Influence of Fiber Input Power**

The eye diagrams of the binary signal and the optically encoded duobinary signal at 193.2THz and at 6dBm input power are shown in figure 6.

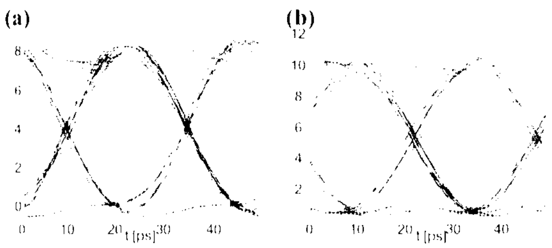


**Figure 6: (a) Binary 100GHz (b) Duobinary 50GHz @ ch: 193.2THz, 80km SSMF, 6dBm**

The dispersion tolerance of the binary and duobinary signal at 193.2THz is investigated at a fiber input power per channel of 6dBm. The results are shown in figure 7.

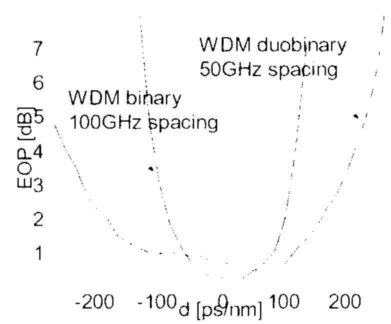


**Figure 7: Dispersion Tolerance @ 6dBm**

**Discussion**

It is well known, that by means of duobinary encoding the spectral occupancy is roughly devided by two /4/. This allows to apply the duobinary interleaving concept to reduce the channel spacing of an existing Nx40Gb/s WDM system from 100GHz to 50GHz. In /4/ single channel considerations were made that show 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 50GHz spacing than for the existing WDM system with 100GHz 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 armed Mach-Zehnder modulator after electrical lowpass filtering are avoided /5/. There is also no spectral broadening, when the encoding is implemented behind the Mach-Zehnder that has a nonlinear characteristic.

**Conclusion**

To our knowledge, duobinary encoding of several channels with one optical transversal filter is a completely new approach. Duobinary encoding with an OTF avoids fundamental problems that occur when electrical lowpass filters are used for duobinary encoding. We showed that just two OTFs 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 precoder is used at the transmitter. We demonstrated a good performance of this DWDM duobinary system with a spectral efficiency of 0.9b/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., *10.2Tbit/s (256x42.7Gbit/s PDM/WDM) transmission over 100km TeraLight fiber with 1.28bit/s/Hz spectral efficiency*, OFC, 2001, PD25-1

/2/ K. Yonenaga et al., *320Gbit/s WDM repeaterless transmission using fully encoded 40 Gbit/s optical duobinary channels with dispersion tolerance of 380ps/nm*, Electronics Letters, 2000, vol. 37, no. 2, pp. 109-110.

/3/ K. Sasayama et al., *Coherent Optical Transversal Filter Using Silica-Based Waveguides for High-Speed Signal Processing*, Lightwave Tech. vol. 9 no. 10 pp. 1225-1230.

/4/ W. Kaiser et al, *SPM Limit of Duobinary Transmission*, ECOC 2000, vol. 3, 7.2.2, pp. 31-33.

/5/ T. Nielsen et al., *Enabling techniques for DWDM transmission systems having high spectral efficiencies*, ECOC 2000, vol.3, 7.1.3, pp. 45-47.