# FIELD TRIAL OF OPTICAL DUOBINARY TRANSMISSION OVER 1720 km AT 10 Gb/s

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***Abstract:*** *Optical duobinary transmission over 1720 km is successfully demonstrated in a field trial within a fully transparent German - wide WDM network. This proves the applicability of duobinary modulation for ultra long haul transmission.*

## Introduction

Optical duobinary transmission as an advanced modulation format has been intensively studied in the last few years offering key benefits for 40 Gb/s transmission systems like improved dispersion tolerance and increased spectral efficiency. For 10 Gb/s systems the enhanced dispersion tolerance can be directly converted into an enlarged uncompensated transmission distance of up to 252 km over Standard Singlemode-Fiber (SSMF) /1/. Or from an application point of view it can be used for a very simple link design (only transmission fiber) enabling a repeaterless and uncompensated transmission over 225 km with SSMF /2/. However, some potential drawbacks of this modulation format (like PRBS length dependence, precoder implementation difficulties or overall transmitter setup complexity) are still under discussion and therefore delay a field deployment. Indeed, only one single-span field trial over 156 km without dispersion compensation is reported /3/. The implementation of duobinary modulation format in combination with a multi-span dispersion managed optical link has not been published so far.

In this paper, we investigate the performance of optical duobinary transmission within a fully transparent German - wide WDM network. The results of this field trial point out the applicability of this modulation format for ultra long haul transmission.

## Transmitter/receiver setup and network configuration used for the field trial

The 10 Gb/s transmitter (Tx) with external modulation is capable of generating both binary and duobinary signals. A chirp-free single-arm Mach-Zehnder-modulator is used for both modulation formats /1/. For duobinary encoding a Gaussian shaped lowpass filter with a cutoff frequency of 2.6 GHz is implemented. No precoder is used in this experiment.

A standard binary (NRZ) optically preamplified receiver (Rx) is used for both modulation formats. No modification is necessary for duobinary transmission.

A fully transparent German - wide WDM network serves as a test bed for this field trial (Fig. 1). The test-network basically consists of a link interconnecting the German cities of Berlin and Darmstadt. The link is equipped with an 8-channel WDM-system at a channel spacing of 200 GHz. The total link length of about 860 km is composed of various lengths of SSMF in deployed optical transmission cables. Manually reconfigurable OXC's in Berlin, Hannover, and Darmstadt enable flexible routing of arbitrary optical channels and, therefore, emulate a transparent optical network. Ultimately the optical signal can be looped back transparently and transmitted over the double link length (1720 km).

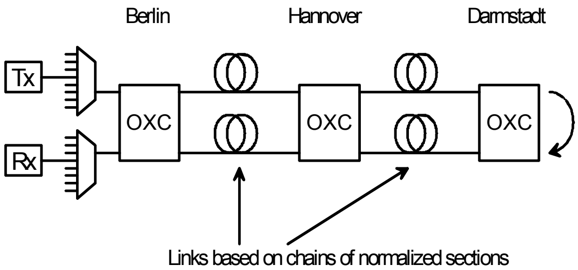


**Fig. 1: System setup of used German - wide WDM network. The signal is looped back transparently at Darmstadt leading to a total link length of 1720 km.**

The physical link and thus the dispersion management is realized according to the concept of normalized sections /4/. The idea of normalized sections is to divide the optical link into a set of identical sections and to install identical equipment (i.e. optical amplifiers and Dispersion-Compensating-Modules (DCM)) in each section. With an (numerical) optimized set of transmission parameters (compensating scheme, choice of degree of compensation (DoC) and launched optical input power into SSMF and DCF), a balance between the interacting effects (dispersion and non-linear self-phase-modulation) is established, resulting in a significant improvement of the transmission performance.

In /5/ NRZ-transmission experiments at a data-rate of 10 Gb/s over distances of up to 1720 km are demonstrated successfully in this WDM network.

The dispersion map of channel #4 ($\lambda$ = 1552,52 nm) for the direction Berlin – Darmstadt is shown in Fig. 2. The counter direction is similar. It is obvious that the total link dispersion varies symmetrically around the zero-dispersion value. The optimum degree of compensation (DoC) was identified as 99% /4/. However, due to different dispersion-slope values of SSMF and DCM each channel of the WDM-system has a different DoC. Thus, the DoC varied from 100% to 97% within the spectral width of 11 nm. The resulting residual dispersion for the used channel is about 200 ps/nm corresponding to a DoC of 98,4%.

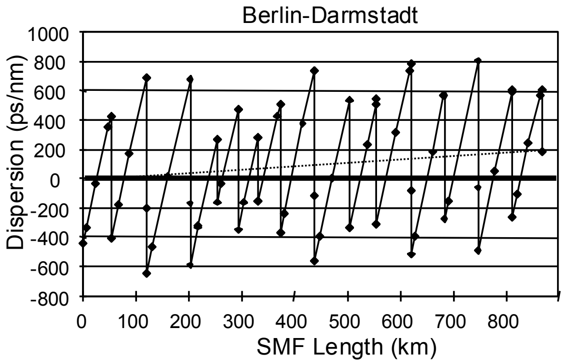


**Fig. 2: Dispersion map of the link Berlin – Darmstadt for the used channel.**

### Transmission results and discussion

The obtained transmission results for standard binary (NRZ) transmission are stated with BER measurements displayed in Fig. 3. A back-to-back receiver sensitivity (BER of $10^{-9}$) of -35 dBm and a total system penalty of 4 dB can be recorded. This serves as a reference. In the duobinary case the corresponding values are -31.5 dBm and 2.5 dB. The slight degradation of the back-to-back sensitivity is typical for duobinary transmission due to different eye shape. This could be improved with an optimization of the decision threshold, but is not done here.

As expected both formats show similar performance for this dispersion managed link. Thus, an alternative usage of both formats is possible.

For further illustration of the transmission performance eye diagrams of duobinary modulation in back-to-back condition and after 1720 km are depicted in Fig. 3. Some overshoots are visible indicating that the launch power into some fiber section is quite high.

During the experiments a non-negligible dependence of the link on polarization effects is experienced. The average differential group delay is identified as about 20 ps. To counterbalance this effect the input polarization is optimized repeatedly with a polarization controller.

### Conclusion

Although the deployed WDM network with a dispersion management approach based on normalized fiber sections is optimized for standard binary (NRZ) transmission, optical duobinary modulation can be used alternatively showing similar performance. No modification of link design and dispersion management is required. The results of this field trial encourage further investigation of duobinary modulation for ultra long haul transmission systems.

### References


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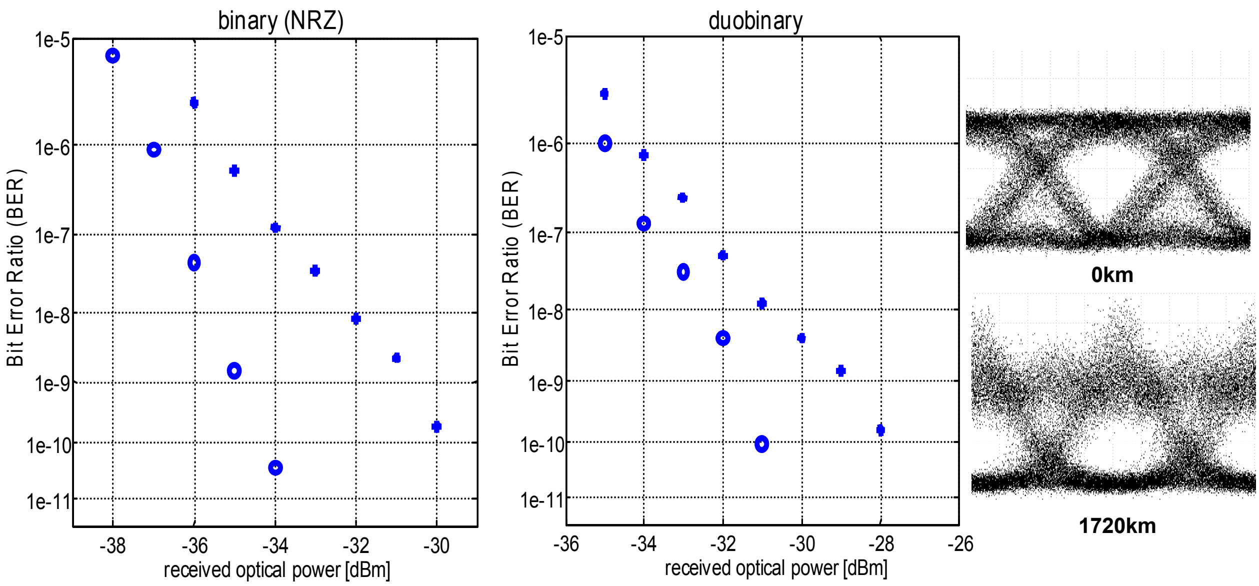


**Fig. 3: BER measurements at 10 Gb/s for both modulation formats: standard binary (NRZ) (left) and duobinary (right) transmission in back-to-back condition (0 km (o)) and after the total link with 1720 km (*). Measured eye diagrams for duobinary transmission at 0 km and after 1720 km.**