Abstract - We present a transmitter setup for optical duobinary transmission with reduced complexity resulting from a simple precoder and from using a standard single-arm Mach-Zehnder-modulator. With this setup data transmission at 10Gb/s over a record length of 252 km uncompensated SSMF is demonstrated.

I. INTRODUCTION

Optical duobinary coding is an effective method in high-speed optical transmission systems to increase dispersion tolerance, to improve spectral efficiency and to reduce the sensitivity to non linear effects. These benefits are essential advantages for dense WDM-transmission systems and have been reported for 10Gb/s- and 40Gb/s systems in [1, 2] and [3], respectively.

Inherent for duobinary coding as a form of partial response signaling is the need for a precoder in order to avoid error propagation and additional hardware complexity at the receiver. With such a precoder, a conventional (binary) optical receiver can be used. An implementation of a duobinary precoder in a straightforward way uses a logic EXOR-gate with a feedback tap with one bit delay. But this feedback tap is hard to implement at high data rates.

In addition, common to all reported high-speed transmission experiments is the use of a duobinary transmitter with a dual-arm Mach-Zehnder modulator (MZM). However, due to dual-arm configuration this setup requires the parallel implementation of two duobinary encoders and two modulator drivers with increased symmetry requirements on the overall setup and the used components.

II. DUOBINARY CODING: OVERVIEW AND THEORETICAL LIMIT

Fig. 1 shows both the schematic and the possible hardware implementation of duobinary coding and decoding with corresponding functional blocks. The spectral shaping of the precoded data b(k) due to duobinary coding results in a bandwidth reduction of about one half compared to conventional binary modulation [4]. Therefore, as a theoretical limit, the uncompensated transmission distance can be increased by a factor of 4. Considering a practical maximum distance at 10 Gb/s of about 80km for binary modulation as a reference, experimental results with a maximum of 243km [1] for duobinary coding have been reported, leading to an improvement of a factor 3.

III. SIMPLE DUOBINARY PRECODER

Up to now, almost all optical duobinary transmission experiments were performed without a precoder. Due to the properties of the commonly used pseudo random bit sequences (PRBS) the precoder output bit stream is identical to its time delayed input bit stream. Therefore, the functionality of the precoder can be omitted for laboratory use, however, transmitting actual data traffic with
duobinary coding without a precoder is not possible. A direct implementation of a duobinary precoder uses an inverter, an EXOR gate and a feedback tap with one bit delay (Fig. 2). Both, the feedback itself using microstrip lines and the exact adjustment of the delay time ($T_b$) are critical and hard to implement at high data rates. Only one hardware realization effort in this manner is reported so far [5] but with limited operation capabilities due to this external feedback tap. In [6] a 1-chip precoder IC operating at 10Gb/s was used implementing the EXOR gate with an internal “on-chip” feedback. However, upgrading this precoder structure to higher bitrates seems still be very difficult since in [7] a precoder IC module is reported overcoming this speed limit by parallel processing of the precoding before electrical multiplexing with data rates of one half or one quarter of the transmission bit rate. Our proposal of a simple realization of the precoder is shown in Fig. 2. The functionality of the precoder can be established connecting an inverter and an AND-gate followed by a toggle flip flop (T-FF), and therefore using standard logic ICs. No external feedback is required since the recursion is an integral function of the T-FF. Consequently, this precoder structure using only feedforward building blocks avoids all problems with implementation and adjustment. Besides, an upgrade to higher bitrates or a single-chip integration can be done straightforward. In our hardware setup we used commercially available standard 10 Gb/s logic ICs. Fig. 3 shows measured bit sequences at 10Gb/s and illustrates the operation of the precoder.

![Precoder (schematic)](image)

**Fig. 2. Simple realization of duobinary precoder with AND-gate and T-Flip-Flop.**

**IV. DUOBINARY TRANSMITTER SETUP**

The conventional duobinary transmitter setup common to all reported experiments is displayed in Fig. 4 (top). It consists of a dual-arm Mach-Zehnder modulator, a duobinary filter and a driver amplifier for each modulator arm driven with the regular and the inverted data signal.

![Pattern-Generator](image)

**Fig. 4. Conventional duobinary transmitter setup with dual-arm MZM (top) and our proposed transmitter configuration with reduced complexity with a standard single-arm MZM (bottom).**

Our proposed transmitter setup is shown in Fig. 4 (bottom) using a standard single-arm Mach-Zehnder modulator, a single duobinary filter and a single driver amplifier. Thus, this setups avoids all symmetry requirements. The single-
arm MZM with internal push-pull configuration provides the same amplitude and phase modulation capabilities as a dual-arm MZM (assuming identical complementary input signals). Internal push-pull operation can be established using an MZM layout with a center electrode and symmetrical ground plates. Using such a single arm MZM for our duobinary coding application implicates the actual innovation in our setup resulting in dramatically reduced complexity and in an improved transmission performance.

V. TRANSMISSION EXPERIMENTS AND RESULTS

In order to evaluate the performance of our proposed transmitter setup we performed transmission experiments and measured the receiver power versus BER for various fiber lengths. Experimental results are displayed in Fig. 5 and 6. Our test setup comprises an inline optical amplifier (placed after 125km of SSMF) and a standard preamplified optical receiver. The fiber input power was chosen to 8dBm according to the results of [2]. For input powers higher than this ‘nonlinear duobinary limit’ the dispersion tolerance of this modulation format is starting to decrease substantially [2]. The measured eye diagrams of duobinary transmission are displayed in Fig. 5.

Both, a typical duobinary eye shape in back-to-back condition is shown with the use of our simple single-arm MZM setup and only slight degradations after 200km SSMF can be observed. The eye diagram after 252km is distorted but error free transmission is still possible. BER measurements at this distance show a receiver sensitivity of about –25dBm (BER=10^-9) and a penalty compared to back-to-back of about 6 dB, see Fig. 6. Note, that a negative penalty for transmission distances under 200km can be observed which is typical for duobinary transmission. For BER measurements a PRBS length of 2^23-1 was used. Achieving an uncompensated length of 252km of SSMF is a step towards the theoretical limit of duobinary transmission.

VI. CONCLUSION

Both, a simple duobinary precoder implemented with standard logic ICs and a single-arm MZM transmitter configuration with reduced complexity and components requirements are presented. With this setup a record length of 252km of SSMF can be bridged without any dispersion compensating device. This approach demonstrates a step of getting closer to the potential of this modulation format.

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