Implementation of precoder for high-speed optical DQPSK transmission

M. Serbay, C. Wree and W. Rosenkranz

A precoder concept for high-speed optical differential quaternary phase shift keying (DQPSK) is presented. By excluding external feedback paths, limitations due to circuit and signal propagation delays can be overcome. Operation is demonstrated by transmitting pseudorandom binary sequences with a length of \(2^{31} - 1\) at 20 Gbit/s with a bit error ratio of \(10^{-10}\). We show experimentally RZ-DQPSK transmission of PRBS processor bits of the current bits in order to increase the tolerance towards nonlinear effects and dispersion [1-6], however the RZ-pulse carving is not necessary for the prelocalization component required in the transmitter.

In previous DQPSK transmission experiments the precoding at high-speed data rates was omitted because for transmitted pseudorandom binary sequences (PRBS) the expected data can be programmed into the logic resulting in two binary input streams \(d_I(k), d_Q(k)\) and two output streams \(d_I(k)\) and \(d_Q(k)\), operating at half the data rate each. The logic operations are described as:

\[
d_I(k) = (a_I(k) \oplus a_Q(k)) \oplus d_Q(k - 1)
\]

\[
d_Q(k) = (((a_I(k) \oplus a_Q(k)) \land d_Q(k - 1)) \land a_Q(k)) \lor d_I(k - 1)
\]

In the above formulae \(\oplus\) denotes exclusive or (XOR) operation, \(\land\) denotes the AND operation and \(d_Q(k - 1), d_I(k - 1)\) are the predecessor bits of the current bits \(d_I(k), d_Q(k)\), respectively. In a second step feedback paths are omitted as proposed in [8]. The block diagram of the resulting setup is shown in Fig. 1 where D-FF, T-FF denote delay and toggle flip-flops, respectively. The precoder was built with commercially availabile high-speed logic gates. It is worth noting that the delay of the signal propagation, caused by the logic gates and RF cables, has to be taken into account for the arrangement of the logic gates.

The precoder was tested in a testbed (see Fig. 2). The optical signal was generated by a distributed feedback (DFB) laser, operating at 194.665 THz. For RZ-pulse carving, an MZM driven by a 10 GHz clock signal with amplitude \(V_o\) resulting in a duty cycle of 50% was used. As a DQPSK transmitter we used a serial structure according to [4]. The precoded bits \(d(k)\) for the in-phase part of the optical signal were amplified to \(2V_o\) and then fed into one MZM in push-pull mode. It was biased in the zero of its characteristic. The optical propagation time from the MZM to the PM was 10.5 ns. To synchronise the data for in-phase and quadrature components on the optical carrier, the precoder output \(d_I(k)\) was also delayed by 10.5 ns before it was amplified to \(1/2 V_o\) and fed into the PM. The electrical delay line consisted of RF cable of the appropriate length, a phase shifter and a limiting amplifier for signal reshaping to overcome the lowpass characteristic of the RF cable.

For measuring the receiver sensitivity the optical signal passed a variable attenuator before it was amplified by a two-stage erbium-doped fibre amplifier (EDFA). The small-signal gain of the EDFA was 32 dB, the noise figure 4.5 dB. An optical filter with a 3 dB bandwidth of 250 GHz suppressed the out-of-band ASE noise of the optical amplifier.

The DQPSK demodulator consists of an MZDI followed by a balanced receiver. The delay in one arm of the MZDI corresponds to one symbol duration plus a phase shift of \(\pm \pi/4\) with respect to the optical carrier period. For BER measurements the data of the in-phase and the quadrature component of the signal were measured separately one after the other, in order to avoid a second demodulator.

For every measurement the input data \(a_I(k)\) and \(a_Q(k)\) of the precoder consisted out of two 10 Gbit/s PRBS of the same length. To ensure that both sequences were uncorrelated one input was inverted and delayed by 2.5 ns. The BER measurements were performed for different PRBS lengths.

Experimental results and discussion: To demonstrate the logic operation, the waveforms of the precoder input and output signals are plotted for a short PRBS input of length \(2^3 - 1\) in Fig. 3, where one can verify the correct function of the precoder. As an example, consider \(k = 6\). One can read from Fig. 3 the values for \(a_I(6), a_Q(6), d_I(5)\) and \(d_Q(5)\). According to (1) and (2) the resulting values for \(d_I(6)\) and \(d_Q(6)\) are \(d_I(6) = 1\) and \(d_Q(6) = 0\), which is verified in Fig. 3.

Next, the receiver sensitivity was measured for different PRBS lengths, using the precoder. For comparison the precoder was then...
omitted and the receiver sensitivity was measured for PRBS by programming the BERT with the expected bit sequences according to [4]. The measurement results obtained using the precoder and PRBS of lengths of $2^{15} - 1$ and $2^{31} - 1$, as well as the results for a PRBS with the length of $2^{15} - 1$, where the precoder was omitted, are plotted in Fig. 4.

The function of the precoder was also verified by precoding data sequences which do not have the unique PRBS properties. The pattern generator (PG) and the BERT were programmed with the same periodically repeated $2^{15}$–1 randomly equally likely selected bits. The measured BER values did not differ from the values of a precoded PRBS, thus showing that the precoder operates correctly.

The differences between the BER values with and without the use of the precoder result from the lowpass characteristics of the logic gates. The differences between the two tributaries (in-phase and quadrature data), as well as the differences between PRBS length of $2^{15}$–1 and $2^{31}$–1 bits using the precoder, are within the measurement accuracy limited mainly by the MZDI stability.

**Conclusions:** We proposed and implemented a DQPSK precoder setup for high-speed transmissions in fibre optic systems. With this setup, BER measurements of RZ-DQPSK transmission with long PRBS of length $2^{31} - 1$ as well as with arbitrary payload data were achieved for a bit rate of 20 Gbit/s. With this precoder a missing key component for future high-speed optical DQPSK transmissions is available.

© IEE 2004

*Electronics Letters* online no: 20046312
doi: 10.1049/el:20046312

M. Serbay, C. Wree and W. Rosenkranz (Chair for Communications, University of Kiel, Kaiserstr. 2, 24143 Kiel, Germany)

E-mail: mse@tf.uni-kiel.de

**References**


