1.6 Gbit/s Real-Time Synchronous QPSK Transmission with Standard DFB Lasers

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Abstract *Using standard DFB lasers, 1.6 Gbit/s QPSK data is demodulated and recovered coherently and synchronously in real-time, faster than ever before. BER after 63 km of fiber is well below the FEC threshold.*

Introduction

Coherent optical transmission, in particular QPSK transmission, allows a more efficient utilization of available bandwidth of existing optical fiber together with a robustness against chromatic and polarization mode dispersion. Synchronous demodulation promises ultimate OSNR performance, which for QPSK outperforms the asynchronous or interferometric one by >2 dB. In today's economic environment, the ultra-narrow linewidth lasers required to implement a phase-locked loop for carrier recovery [1] are widely believed to be too costly. In contrast, a feedforward carrier recovery scheme [2] relaxes the sum linewidth requirement to about 0.001 times the symbol rate, which is in the reach of standard, low-cost DFB lasers. Comparable schemes have been verified offline, using oscilloscope-sampled 10 Gbaud QPSK data from coherent systems [3, 4], and online (in real-time) for PSK signals at low data rate with conventional DFB lasers [5].
In this paper we present the implementation of a QPSK transmission system with standard DFB lasers and real-time synchronous demodulation and data recovery, reaching a data throughput of 1.6 Gbit/s.

Experimental Setup

The transmitter uses a DFB signal laser and a QPSK modulator driven with 2x800 Mbit/s PRBS data (Fig. 1). Normally the I&Q data is Gray-encoded to form a quadrant number, which is modulo 4 differentially encoded to determine the quadrant of the optical phase. In this setup, identical PRBS are used as I&Q modulator driving data, mutually delayed by 8 symbols for decorrelation purposes, and differential quadrant encoding is not implemented. To account for this omission and to enable BER measurements, an appropriate bit pattern is programmed into the bit error rate tester.
After transmission through 63 km of standard single mode fiber, an optical preamplifier is followed by a ~20 GHz wide bandpass filter. The coherent receiver features a second DFB laser as its local oscillator and manual polarization control. The two optical signals are superimposed in a $LiNbO_3$ 90° optical hybrid and detected with two photodiode pairs. The resulting electrical I&Q signals are amplified before being sampled with 5-bit analog-digital converters (ADCs).

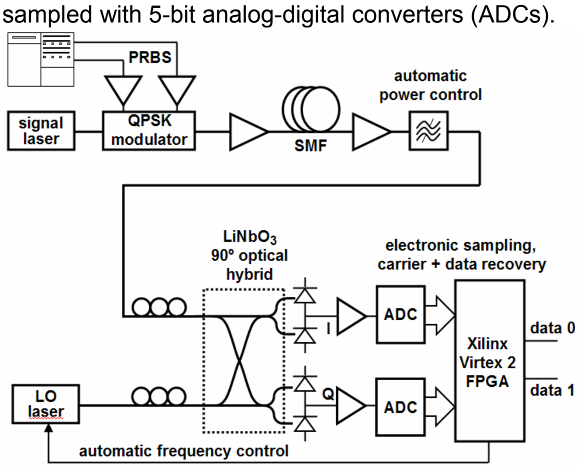

Fig. 1: 2×800 Mbit/s QPSK transmission setup with a real-time synchronous coherent digital I&Q receiver.

The ADCs interface with a Xilinx Virtex 2 FPGA where electronic carrier and data recovery is implemented [6]. The data recovery includes a differential modulo 4 decoding of the received quadrant number, to prevent occurring quadrant phase jumps of the recovered carrier from falsifying all subsequent data. Most processing occurs in parallel units at a rate which is 16 times lower than the symbol rate. The results of every fourth unit are re-assembled to form a sequential bit stream. The measured BER value is multiplied by 2 to take into account the effect of two consecutive bit errors occuring due to the differential decoding scheme used in the receiver. The resulting BER has to be considered as worst case because errors caused by phase jumps only generate a single bit error due to ASE noise instead of an error pair. Therefore, in the region of the BER floor, the real BER value will be below the reported value.
The automatic frequency control is implemented as follows: The observed carrier phase jumps between subsequent symbols are output from the FPGA and integrated. The resulting signal controls a portion of the LO bias current.

Measurement Results

The –3 dB sum linewidth of the DFB lasers (JDSU) was measured as 4 MHz. Due to insufficient laser bias current filtering this exceeds the 2 MHz value expected from the data sheet.

Fig. 2 shows the modulated heterodyne electrical spectrum recorded after the optical 90° hybrid in the receiver.

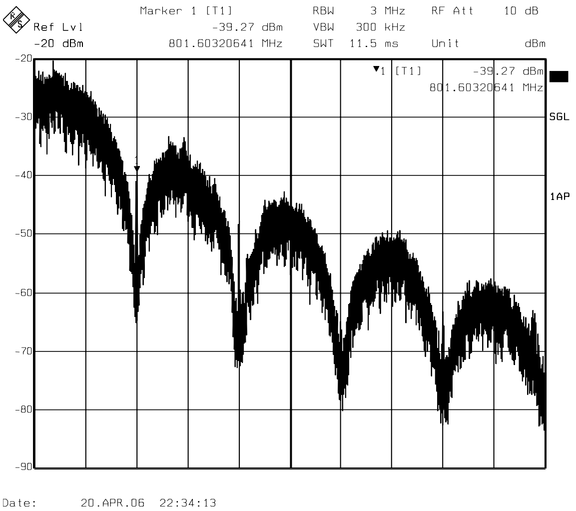

Fig. 2: Modulated electrical spectrum after the optical 90° hybrid in the receiver at 2x800 Mbit/s data rate.

Fig. 3 shows the BER vs. received power for 1.6 Gbit/s transmission over distances of 2 and 63 km, using 2^7-1 and 2^{31}-1 PRBS. The best measured BER was $2.7 \cdot 10^{-4}$ with 2^7-1 PRBS transmitted over 2 km, and it was $4.4 \cdot 10^{-4}$ for a 2^{31}-1 PRBS. Both PRBS could be detected until the preamplifier input power was set below -52 dBm.

The BER floors for 63 km distance are slightly higher than for 2 km, $3.4 \cdot 10^{-4}$ for the 2^7-1 PRBS and $4.0 \cdot 10^{-4}$ for the 2^{31}-1 PRBS. This is probably due to the lack of a clock recovery circuit in the receiver and the resulting usage of the transmitter clock, which introduced phase noise.

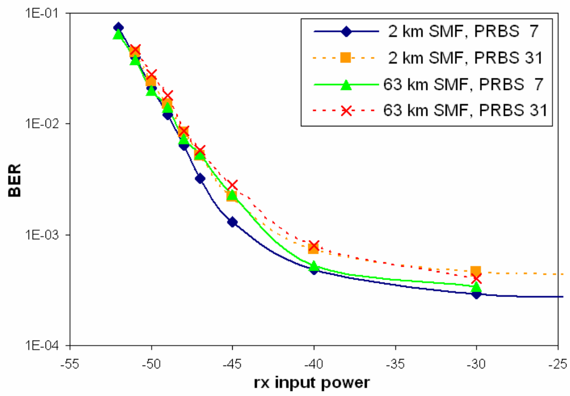

Fig. 2: Measured BER vs. optical power at the preamplifier input at 1.6 Gbit/s data rate.

The transmission system was tested with two QPSK modulators; a GaAs type with a total insertion loss of 18.8 dB and a $LiNbO_3$ version (Photline) having 12 dB loss. Both modulators gave identical BER floors.

Discussion

A FEC coding scheme with 7% overhead is able to recover (quasi) error-free data for a raw BER below 0.1%. Our 1.6 Gbit/s QPSK transmission therefore corresponds to an error-free data rate of 1.5 Gbit/s, assuming the presence of such an FEC.

For various data rates, BER floor values are plotted as a function of the product of the measured sum linewidth times the symbol duration T (Fig. 4). The floor drastically drops with the symbol duration. Very good performance with standard DFB lasers can be achieved at 10 Gbaud, which corresponds to 20 Gbit/s data throughput, or even 40 Gbit/s with additional polarization multiplex.

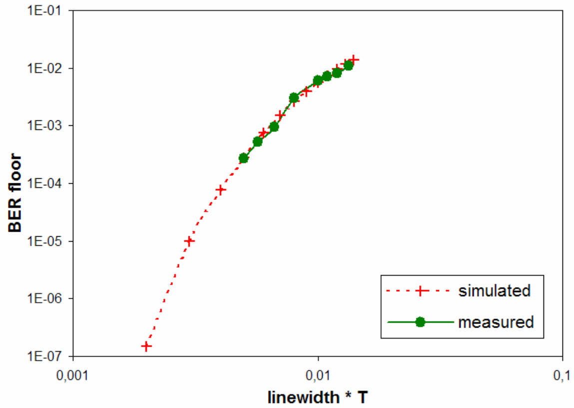

Fig. 4: BER floor for different products of linewidth times symbol duration T.

Summary

We have demonstrated synchronous QPSK transmission using commercially available DFB lasers and a real-time digital receiver for data recovery. 1.6 Gbit/s QPSK data was transmitted over 2 km and 63 km with FEC-compatible performance. To our knowledge, this is the fastest reported real-time QPSK transmission.

References

1 F. Derr, *IEEE JLT,* Vol. 10 (1992), 1290-1296.

2 R. Noé, *IEEE JLT*, Vol. 23 (2005), pp. 802-808

3 M.G. Taylor: Proc. ECOC-IOOC 2003, We4.P.111, Sept. 21-25, 2003, Rimini, Italy

4 S. Tsukamoto et al: Proc. OFC/NFOEC2005, PDP29, March 6-11, 2005, Anaheim, CA, USA

5 R. Noé et al: Proc. ECOC '92, Th PD I.5, Vol. 3, pp. 867-870

6 R. Noé, *IEEE PTL*, Vol. 17 (2005), pp. 887-889