Synchronous QPSK transmission at 1.6 Gbit/s with standard DFB lasers and real-time digital receiver

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In a coherent and synchronous QPSK system with real-time data recovery and standard DFB lasers a data throughput of 1.6 Gbit/s is achieved, faster than ever reported. After 63 km of fibre the BER is well below the FEC threshold.

Introduction: The efficient utilisation of available bandwidth of existing optical fibre and robustness against chromatic and polarisation mode dispersion are properties that have revived the interest in coherent optical transmission, in particular QPSK transmission. Ultimate OSNR performance is promised by synchronous demodulation, which for QPSK outperforms the asynchronous or interferometric one by >2 dB. In today's cost-conscious economic environment, ultra-narrow linewidth lasers required to implement a phase-locked loop for carrier recovery [1] are widely believed to be prohibitive. In contrast, a feedforward carrier recovery scheme [2] relaxes the sum linewidth requirement to about 0.001 times the symbol rate, which allows the use of standard, low-cost DFB lasers. The first real-time data recovery for a QPSK transmission system with a data rate of 800 Mbit/s was published in [3]. Other comparable schemes have been verified offline, using oscilloscope-sampled 10 Gbaud QPSK data from coherent systems [4–6], and online (in real-time) for PSK signals at low data rate with conventional DFB lasers [7]. In this Letter we present the implementation of a synchronous QPSK transmission system with a real-time digital I&Q receiver and standard DFB lasers. The data throughput is doubled compared to [2], reaching 1.6 Gbit/s.

Experimental setup: The transmitter uses a DFB signal laser and a QPSK modulator driven with 2×800 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 eight symbols for decorrelation, and differential quadrant encoding is not implemented. To take this omission into account and to enable bit error rate (BER) measurements, appropriate bit patterns are programmed into the BER tester.

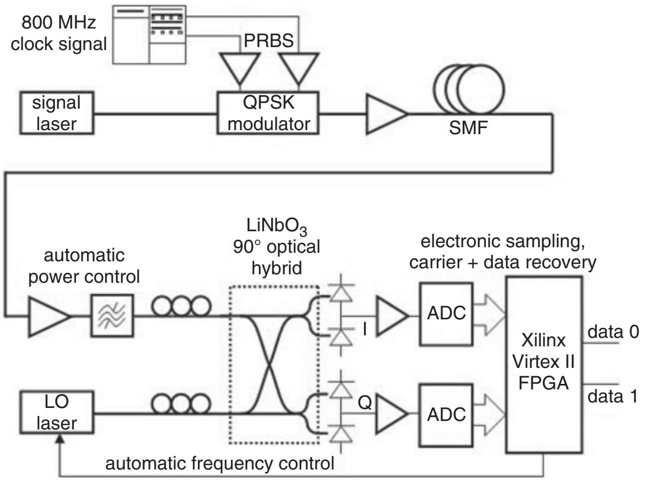

Fig. 1 *2 × 800 Mbit/s QPSK transmission setup with real-time synchronous coherent digital I&Q receiver*

After transmission through 63 km of standard singlemode fibre, the signal is optically preamplified and filtered by an ~20 GHz wide bandpass. The coherent receiver features a second DFB laser as its local oscillator, and manual polarisation 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 analogue-digital converters (ADCs).

The ADCs interface with a Xilinx Virtex 2 FPGA where electronic carrier and data recovery is implemented [8]. The data recovery includes a differential modulo 4 decoding of the received quadrant number, to prevent 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 reassembled to form a sequential bit stream. The measured BER value is multiplied by 2 to take into account that the differential decoding scheme used in the receiver can generate two consecutive bit errors. The resulting BER has to be considered as worst case because errors caused by carrier phase quadrant jumps only generate a single bit error 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 measured −3 dB sum linewidth of the DFB lasers (JDS Uniphase) was 4 MHz. Fig. 2 shows BER against 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 2.7×10^{-4} with 2^7-1 PRBS transmitted over 2 km, and it was 4.4×10^{-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, 3.4×10^{-4} for the 2^7-1 PRBS and 4.0×10^{-4} for the $2^{31}-1$ PRBS. This is probably owing to the lack of a clock recovery circuit in the receiver and the resulting usage of the transmitter clock, which introduced phase noise.

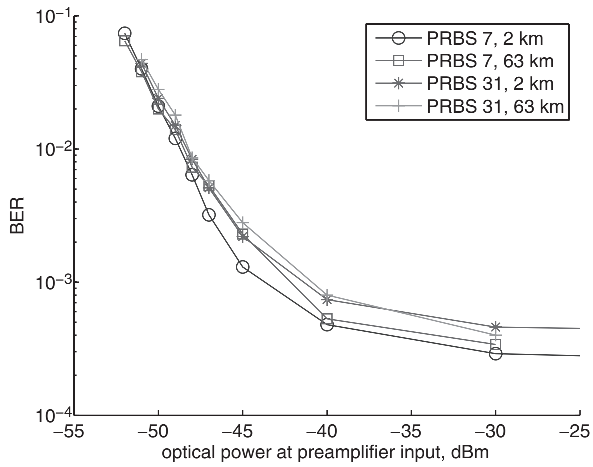

Fig. 2 *Measured BER against optical power at preamplifier input at 1.6 Gbit/s data rate*

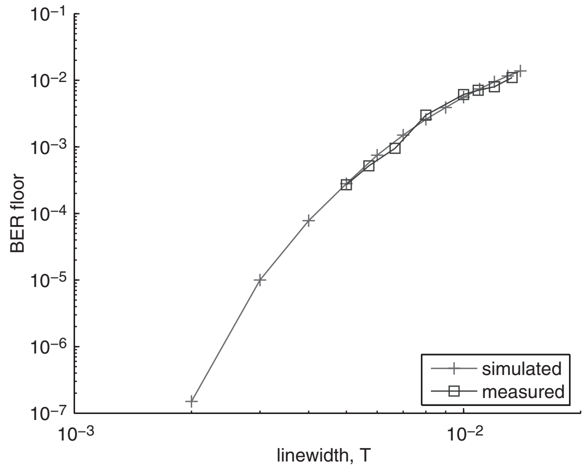

Fig. 3 *BER floor for different products of sum linewidth times symbol duration T*

Discussion: An 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 against the product of measured sum linewidth and symbol duration T (Fig. 3). The floor drastically drops when T is reduced. 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 polarisation multiplex.

Conclusion: 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 and 63 km with FEC-compatible performance. To our knowledge, this is the fastest reported real-time QPSK transmission.

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