

Experimental demonstration of 23.6-Gb/s OFDM with a colorless transmitter

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Abstract

We experimentally demonstrate 23.6-Gb/s optical OFDM (20-Gb/s after coding) with a colorless transmitter, realized by optical IQ multiplexing. In combination with 8-QAM coding, DACs with only 4-GHz bandwidth are required to generate the 23.6-Gb/s signal.

1 Introduction

Lately, orthogonal frequency domain multiplexing (OFDM) has received a lot of attention for fiber-optic transmission [1]-[4]. OFDM provides excellent robustness against intersymbol interference and an efficient use of bandwidth as individual subcarriers partly overlap.

When at the transmitter a single ended Mach-Zehnder modulator (MZM) is used, an image band is created mirrored with respect to the optical carrier. This image band reduces the spectral efficiency and the power efficiency of the OFDM transmission system. Therefore, an optical bandpass filter is required to remove the image band at the transmitter [1], [3]. An alternative method to avoid the generation of an image band is by using a complex IQ modulator. Recently, 12-Gb/s OFDM signal has been reported with such a ‘colorless’ modulator [3]. In this experiment the Hilbert transform was used to modulate one sideband only of the optical carrier.

In this paper, we are the first to show optical IQ mixing for OFDM and realize 23.6-Gb/s OFDM with a colorless transmitter. As both sides of the optical carrier are utilized, the DAC requirements are reduced to only 4-GHz.

2 Experimental setup

Fig. 1 shows the experimental setup. Offline, a 23.6-Gb/s optical baseband signal is calculated and uploaded into a Tektronix AWG7102 arbitrary waveform generator (AWG). The maximum sampling rate of the AWG is 10 GHz and thus the bandwidth per output (I and Q) is 5 GHz. With QPSK coding, the maximum data rate that can be generated with this AWG is:

$$2 \text{ outputs} * 2 \text{ bit/Symbol} * 5 \text{ GHz} = 20 \text{ Gb/s}$$

However, this is the data rate before coding, which does not include the overhead required for FEC, preambles and cyclic extension. Therefore, a higher constellation is required in this configuration to generate an OFDM signal with a net data rate of 20 Gb/s. By using 8-QAM instead of QPSK for symbol mapping, the required bandwidth at the AWG per channel is reduced to 4 GHz for a 23.6-Gb/s signal (20 Gb/s after coding) and can thus be realized with our AWG. A 4.5-ns cyclic prefix per OFDM symbol is applied and the FFT size used is 1024, from which 800 channels are used for data transmission. The AWG continuously outputs the in-phase (I) and quadrature (Q) parts of the baseband signal, which are subsequently amplified and fed to an integrated IQ modulator. The integrated IQ modulator has three bias voltages that accurately need to be controlled. Bias ‘A’ and ‘B’ control the phase of the parallel MZMs and bias ‘C’ controls the phase of the outer Mach-Zehnder structure. Bias ‘A’ and ‘B’ are set a couple of mV above the modulator null point so that a

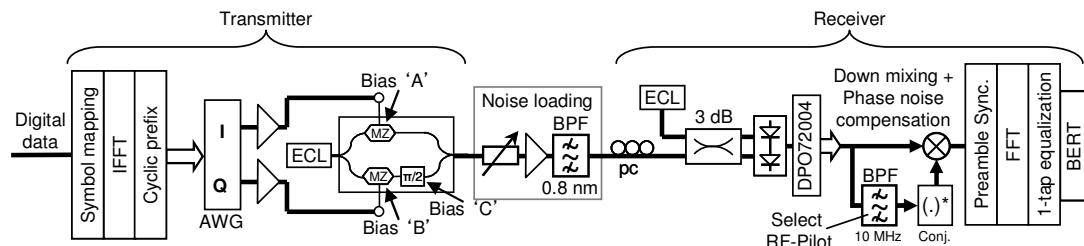


Fig. 1: experimental setup of the 23.6-Gb/s OFDM setup with BPF = band pass filter, ECL = external cavity laser, BERT = bit error ratio tester.

small carrier is present in the signal after modulation. This carrier is used as a pilot tone at the receiver to compensate for phase noise of the local oscillator [5]. Bias ‘C’ is set so that the phase difference between the two arms of the integrated IQ modulator is 90°. At the receiver, the signal is heterodyne detected with a local oscillator (LO), a 3-dB coupler and a balanced detector. The heterodyne receiver is described in more detail in [1], [5].

3 Experimental results

Fig. 2a shows the optical spectrum of the 23.6-Gb/s OFDM signal after modulation. In this spectrum the aliasing products of the AWG can clearly be seen. Due to the unavailability of suitable low-pass filters these aliasing products could in this experiment not be removed from the OFDM signal. Fig. 2b shows the constellation diagram at high OSNR. A non-rectangular 8-QAM constellation was used for symbol mapping since it is known from literature that this constellation provides the maximum symbol distance for 8-QAM [6].

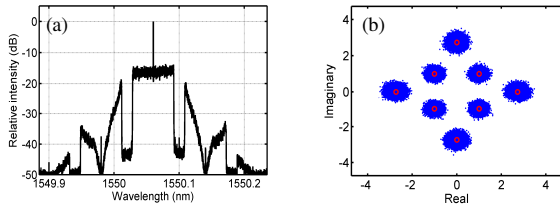


Fig. 2(a) Optical Spectrum of the 23.6-Gb/s OFDM signal (Res. Bw. = 20 MHz), (b) Constellation of 23.6-Gb/s 8-QAM (all subcarriers).

Fig. 3 shows the BER as a function of the OSNR for several OFDM configurations. The 12.5-Gb/s OFDM configuration with QPSK coding is taken as reference measurement. It can be seen that both optical and electrical IQ multiplexing result in practically the same OSNR performance. A more detailed description of the experiment with electrical IQ multiplexing can be found in [5].

The required OSNR for a BER of $1e-3$ is 8.5 dB for 12.5-Gb/s QPSK. A 1.6-dB OSNR penalty is observed for the 12.5-Gb/s 8-QAM constellation. The theoretical difference between QPSK and 8-QAM is 3.7 dB [6]. However, the optical spectrum of 12.5-Gb/s 8-QAM is 1.5x smaller than 12.5-Gb/s QPSK. Taking this difference in spectral width into account a 1.9-dB OSNR penalty is to be expected for 8-QAM with respect to QPSK at the same symbol and data rate. The 0.3-dB difference between the-

ory and experiment can be explained by the fact that the AWG introduces more phase noise at high frequencies (this has earlier been observed in [3] and [4]). Since the baseband of the QPSK 12.5-Gb/s signal is 1.5x wider than the 8-QAM configuration, the AWG induced phase noise penalty is higher for the QPSK configuration.

At 23.6 Gb/s a BER of $1e-3$ is obtained for an OSNR of 13.8 dB. The OSNR penalty between 12.5-Gb/s 8-QAM and 23.6-Gb/s 8-QAM is 3.7 dB. As the optical spectrum of the 23.6-Gb/s 8-QAM signal is about twice as wide, a 3-dB penalty is expected. The extra 0.7-dB OSNR penalty can be explained by the increased phase noise of the AWG that is added at 23.6 Gb/s. Additionally, the alignment of Bias ‘C’ of the complex IQ modulator is more critical at 23.6 Gb/s than at 12.5 Gb/s. A minor offset in Bias ‘C’ might as well contribute to the observed OSNR penalty.

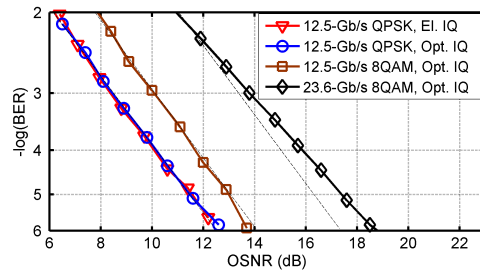


Fig. 3: BER performance of the 12.5-Gb/s and 23.6-Gb/s OFDM signals.

4 Conclusion

We showed 23.6-Gb/s coherent optical OFDM with a colorless transmitter, realized by optical IQ mixing. With an 8-QAM constellation, the bandwidth requirements for the DACs are reduced to 4 GHz for the 23.6-Gb/s signal.

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