# Single Polarization Direct Detection Optical OFDM with 100 Gb/s Throughput: A Concept Taking into Account Higher Order Modulation Formats

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**Abstract:** Several strategies to achieve 100 Gb/s throughput for single polarization DD-OFDM are considered. Based on state-of-the-art in converter technology, using higher order modulation formats a concept aiming at high sensitivity is proposed.

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## 1. Introduction

For a couple of years now, the well-known concept of orthogonal frequency division multiplexing (OFDM) has been studied regarding its suitability for high-speed data transmission over fiber-optic transmission lines. From point of view of simplicity, the implementation using intensity modulation and direct detection (DD-OFDM) is favorable compared to its coherent counterpart CO-OFDM, although it shows less performance in terms of bandwidth efficiency and sensitivity.

A lot of aspects of DD-OFDM have been studied in the past, among them its receiver sensitivity [1,2], robustness towards nonlinearities [3], and its experimental realization targeting at 100 Gb/s throughput with the help of polarization multiplexing [4]. Based on these works, in this contribution it is our intention to suggest a concept as to how a DD-OFDM transceiver could be designed to provide 100 Gb/s throughput with low effort.

To our opinion, the advantages of CO-OFDM over DD-OFDM in terms of sensitivity and bandwidth efficiency are so significant that in order to be an attractive alternative, DD-OFDM needs to focus on its biggest potential, namely to provide the OFDM technology with very low effort in the optical domain. Therefore, we do not believe that polarization multiplexing is really an option for DD-OFDM, although an intelligent solution is suggested in [4]. Instead, we want to show how 100 Gb/s throughput can be achieved by proper exploitation of higher order modulation formats taking into account recent developments in sampling speed of digital-to-analog- and analog-to-digital converters (DACs and ADCs, respectively). While realizing this throughput, we especially focus on the receiver sensitivity. This is for two reasons: firstly, DD-OFDM needs to be competitive with other candidates for 100 Gb/s data rate like DQPSK, and secondly, a high sensitivity will allow for low input power into the optical fiber keeping nonlinear degradations due to Kerr effect low.

## 2. Basic direct detection OFDM experiment with 6 Gb/s throughput

Fig. 1 shows setup and result of a back-to-back measurement. The real-valued OFDM signal is generated using an arbitrary waveform generator (AWG) with 20 GHz sampling frequency. According to 5.8 GHz analog bandwidth of the AWG, the QPSK-modulated OFDM subcarriers are allocated up to 6GHz by appropriate feeding of the input of the 2048-length IFFT. A frequency gap from DC up to 3 GHz is introduced to separate second order nonlinearity from data carriers after squaring operation in the photo diode. Laser wavelength and optical filter center frequency are set to 1539 nm, the ASE noise is of 0.6 nm bandwidth. The modulator is driven with standard deviation $\sigma \approx 0.2 V_\pi$ and biased at $V \approx 0.9 V_\pi$ for low carrier power [2]. Sensitivity of 9 dB OSNR (0.1 nm) is obtained for BER=$10^{-3}$.

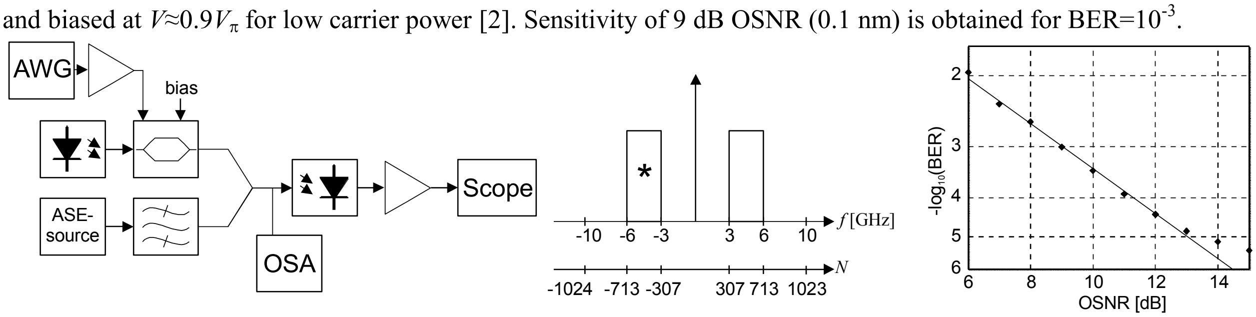


Fig.1. Experimental setup (left), OFDM subcarrier allocation (center), and BER result (right) for 6 Gb/s DD-OFDM b2b measurement.

## 3. Approach to achieve 100 Gb/s throughput

Compared to the experiment, to achieve a net throughput of 100 Gb/s the data rate of 6 Gb/s needs to be increased by a factor of 20 at least. The exact value depends on the FEC scheme, the length of the cyclic prefix which is determined by total link dispersion, and the overhead required for OFDM symbol synchronization and equalization.

In case the factor of 20 (13 dB) would be realized purely by increasing the speed of the whole setup by this factor, a sensitivity of 22 dB for BER=$10^{-3}$ could be obtained. Clearly, the required speed of electronics as well as of modulator and photo diode beyond 100 GHz is not realistic. Instead, other strategies need to be found that allow for higher throughput and that preserve linear scaling of sensitivity with throughput as good as possible.

The experiment above is very inefficient in terms of utilization of DAC and ADC bandwidth. Only ≈15% of the IFFT input is used for data allocation, the other ≈85% are used to generate the frequency gap, to adapt to specifications for the DAC interpolation filter and to generate a real-valued signal. An improvement in efficiency can be achieved, if instead a complex-valued IFFT/FFT is computed, for which ≈60% of the subcarriers is used (e.g. 307 of 512). The IFFT-output is converted by two DACs in parallel. The frequency gap can be generated by means of electrical up-conversion in the transmitter and corresponding down-conversion in the receiver. This concept has been shown experimentally e.g. in [4]. Combining this strategy with improved converter speed beyond 50 Gsamples/s that was announced recently, the throughput may be increased by a factor of ≈2.5·4=10.

For the remaining factor of ≈2, higher-order modulation formats compared to QPSK are required. Here, linear scaling of throughput with sensitivity is not the case, shown by the following example: The bandwidth efficiency is doubled by changing the modulation format from QPSK to 16QAM. When $d$ is the minimum Euclidian distance between two symbols, it may be shown that for 16QAM the mean power is $5d^2/2$ compared to $d^2/2$ for QPSK. When comparing different formats, the sensitivity is approximately the same if $d$ is the same. Thus, 5 times (7dB) higher signal-to-noise ratio is required for 16QAM to achieve the same BER for only 3 dB increase in data throughput.

Fig. 2 shows approximate penalties compared to QPSK for several modulation formats. Since for OFDM the digital modulation format may be selected by software, it makes sense not to restrict to square-QAM formats (e.g. 16-QAM) but also to consider formats like 3-PSK [5] or 6-QAM [6] which show a higher density of symbols for the same minimum $d$. It should be noted that Gray-coding is not possible for those formats, which has been neglected for computing the sensitivity penalty. Thus, the penalties are correct for very low BER but may differ by a few tenths of dB for higher BER. Nevertheless, due to higher symbol density basically formats like e.g. 12-QAM or 21-QAM show a better ratio of sensitivity vs. throughput. Fig. 2 also shows a concept for OFDM signal generation using 21-QAM for which 13 bit are encoded into 3 symbols ($21^3$=9261<$2^{13}$). Analog bandwidth of 15 GHz is used for the 50 GHz DAC. Taking into account < 5 dB penalty due to 21-QAM, sensitivity of ≈27 dB OSNR is expected.

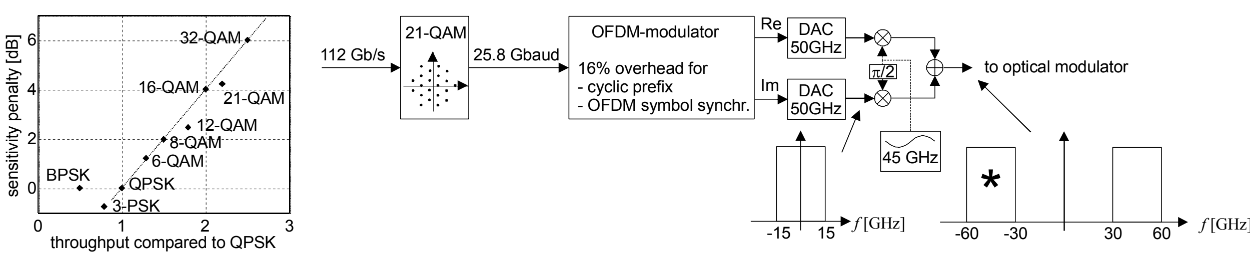


Fig. 2. Sensitivity penalty for several digital modulation formats (left), and block diagram for generation of OFDM modulator signal with 60 GHz bandwidth containing 100 Gb/s net data rate using 21-QAM digital modulation.

## 4. Conclusion

A setup for DD-OFDM with 100 Gb/s throughput without polarization multiplexing is suggested. By using 21-QAM digital modulation, sensitivity of 27 dB OSNR for BER=$10^{-3}$ may be expected.

## 5. References

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