

OFDM Transceiver Design for Optimizing Sensitivity and Long-Haul Performance

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Abstract— Design parameters for optical OFDM transceivers based on intensity modulation and direct detection are considered. Proper selection of modulator bias improves sensitivity by several dB. The length of the guard interval is adapted for uncompensated long-haul transmission.

Index Terms—OFDM, sensitivity, transceiver technology.

I. OFDM IN OPTICS - A BRIEF OVERVIEW

ORTHOAGONAL frequency division multiplexing (OFDM) is known in classical digital communications. Optical communications, however, is currently accelerating its effort to implement sophisticated transmitter and receiver structures to increase data throughput. Consequently, investigation into optical OFDM nowadays is a very hot topic [1-4].

There are two strategies for transmitting the quasi-analog OFDM signal. One solution is given by optical I-Q modulation in conjunction with coherent detection (CO-OFDM) [2,3]. A second method restricts to a real OFDM signal transmitted with intensity modulation and direct detection and is simply called optical OFDM (OOFDM). While CO-OFDM shows higher performance in terms of bandwidth efficiency and receiver sensitivity, OOFDM provides the advantages of OFDM, like robustness towards fiber dispersion, with low effort. Hence, here we focus on the latter approach.

II. OOFDM BASED ON DIRECT DETECTION

A. Back-to-Back System Setup

Fig. 1 depicts the system setup. The binary data stream at 43Gb/s is parallelized and mapped into complex symbols. By means of the choice of symbol mapping (e.g. QPSK, QAM), bandwidth efficiency and sensitivity can be balanced. In this contribution we use QPSK mapping onto 512 subchannels.

The complex symbols are fed into an IFFT. To generate a real output signal, complex conjugate symbols are created appropriately and fed into the IFFT, too. Moreover, half of the input of the IFFT around the DC value is filled with zeros to create an OFDM spectrum that avoids interference with second-order nonlinearity after squaring in the photo diode [1]. Alternatively, this signal can be constructed by means of a complex IFFT followed by electrical I-Q up-conversion. After serialization, the guard interval may be added resulting in the electrical quasi-analog signal to be transmitted over the optical

channel. The signal is clipped appropriately and fed into an optical Mach-Zehnder modulator (MZM). After transmission, a photodiode (PD) converts the optical signal into the electrical domain, where OFDM demodulation and frequency-domain equalization are performed. For back-to-back transmission, the channel is equal to the identical system. In this case, guard interval and equalizer are not required.

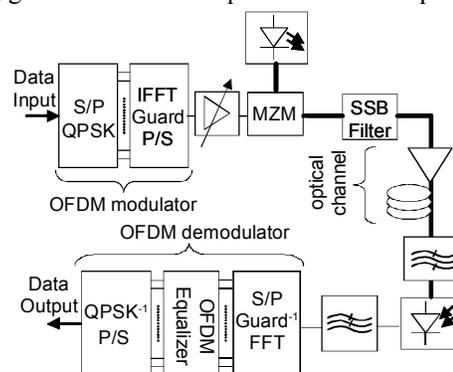


Fig. 1. Setup for OOFDM with intensity modulation and direct detection.

B. Guard Interval and SSB Filtering for Dispersive Fiber

In case of dispersive fiber, linear distortion and crosstalk between OFDM symbols are obtained. To compensate, a guard interval of sufficient length (see section IV) needs to be introduced to allow for frequency-domain equalization (i.e. cyclic convolution) afterwards. However, due to MZM and photodiode the system exhibits nonlinear behavior. By means of first-order analysis of the overall system, it can be shown that the relation between input and output signal is given by the real part of the complex fiber transfer function, i.e.

$$H_{DSB} = \text{Re} \left\{ \exp \left(-j2\pi^2 \beta_2 f^2 L \right) \right\} = \cos \left(2\pi^2 \beta_2 f^2 L \right),$$

where β_2 characterizes chromatic dispersion of a fiber of length L . Depending on the product $\beta_2 L$ the transfer function exhibits nulls in its magnitude resulting in complete suppression of specific OFDM subcarriers. This can be avoided by suppressing the lower sideband of the symmetric spectrum. Then, first order analysis results in an overall transfer function (i.e. including SSB filter and optical fiber) of

$$H_{SSB}(f) = \exp \left[-j \text{sgn}(f) 2\pi^2 \beta_2 f^2 L \right],$$

where $\text{sgn}(f)$ denotes the sign function. $H_{SSB}(f)$ does not show nulls in its magnitude.

III. OPTIMIZING SENSITIVITY

A. Trade-off between Noise Requirements and Nonlinearity

For investigation into receiver sensitivity, SSB filtering and fiber are neglected. Then the nonlinearities of MZM and PD may be combined resulting in the characteristic given in fig. 2. For high linearity, the MZM is biased at its quadrature point.

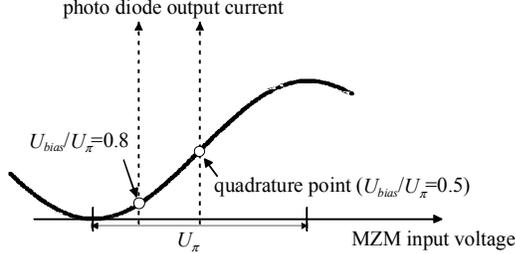


Fig. 2. Combined nonlinear characteristic of MZM and PD. As MZM input voltage is DC-free, the position of the vertical axis depends on the bias point.

Intensity modulation inherently requires a carrier. For fixed bias, carrier power is fixed, too. Now, the amplitude of the zero-mean driving signal is varied. Obviously, there is a trade-off: For low amplitude, carrier power is much higher than the power in the sidebands yielding low sensitivity. For high amplitude, however, the signal suffers nonlinear distortion. The optimum driving amplitude, quantified by its standard deviation normalized by U_π , is shown fig. 3a).

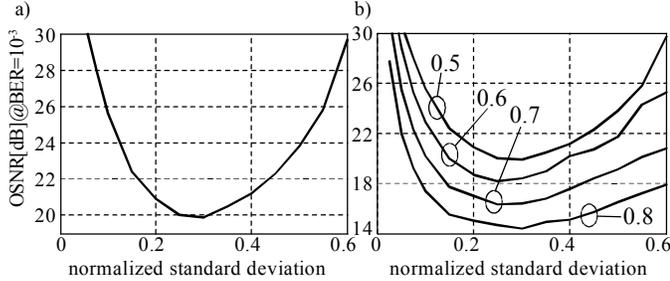


Fig. 3. Required OSNR for $\text{BER}=10^{-3}$ over standard dev. of driving voltage a) when biasing the MZM at quadrature point; b) with different bias points.

B. Improving Sensitivity by Means of Proper Biasing

The results in fig. 3a) show the basic dilemma when MZM is biased at the point of highest linearity: To avoid nonlinear distortion the driving amplitude still has to be chosen low. The power of the optical carrier wastes a high percentage of the total power (e.g. $\approx 80\%$ for $\sigma \approx 0.3 U_\pi$). Therefore, in our approach a variable bias is introduced. Choosing the bias voltage such that carrier power is reduced (i.e. on the characteristic given in fig. 2 we move to the left) improves sensitivity, but at the cost of worse linearity. As long as the resulting degradation does not overcompensate for the benefit due to reduced carrier power, receiver sensitivity increases.

Fig. 3b) shows simulation results for different values of the bias. Sensitivity is increased, but obviously there is not a clear optimum value for the bias. It seems that best performance is achieved the lower the carrier power is. However, this results in high insertion loss of the MZM. Therefore, the bias voltage that is allowed is limited to a certain value (e.g. $0.8 U_\pi$).

IV. GUARD INTERVAL VERSUS TRANSMISSION LENGTH

A. Fiber Impulse Response

As mentioned in section II, the purpose of the guard interval is to suppress crosstalk between neighboring OFDM symbols. Therefore, the length of the impulse response needs to be known. For wireless transmission, the length is determined uniquely by minimum and maximum path delay. For dispersive fiber, however, the impulse response theoretically is of infinite length. Even in a band limited scenario, there is no clearly defined length but the impulse response decays asymptotically down to zero [5]. Therefore, the length of the guard interval for a given amount of dispersion is investigated by simulation in the following.

B. Simulation Results

Fig. 4 depicts the impact of length of guard interval on required OSNR. Clearly, the more dispersion the longer is the required length (given as overhead added to OFDM symbol length). Depending on the length, uncompensated transmission over hundreds of kilometers is feasible. Currently, the required length depending on signal bandwidth and accumulated dispersion is subject of more intensive study.

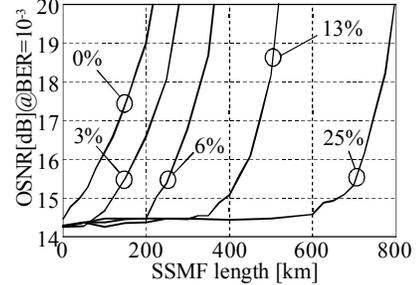


Fig. 4. Required OSNR for $\text{BER}=10^{-3}$ over SSMF length for several values of guard interval length, normalized by OFDM symbol length.

V. CONCLUSION

The impact of OOFDM transceiver design on receiver sensitivity and long-haul performance is shown. Optimizing the bias increases sensitivity by approx. 5dB. Adequate length of guard interval allows for uncompensated transmission length of several hundreds of km of SSMF.

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