Optical Biasing in Direct Detection Optical-OFDM for Improving Receiver Sensitivity

Abdulamir Ali[1], Henning Paul[2], Jochen Leibrich[1], Werner Rosenkranz[1] and Karl-Dirk Kammeyer[2]
[1]*Chair for Communications, University of Kiel, Kaiserstr. 2, D-24143 Kiel, Germany,*
[2]*Department of Communications Engineering, University of Bremen, Otto-Hahn-Allee NW1, D-28359 Bremen, Germany*
E-mail: aal@tf.uni-kiel.de

Abstract: We show that replacing of electrical by an optical biasing minimizes the nonlinearity effect of an optical modulator. This allows the amplitude of the driving signal to be increased which increases the robustness towards distortion.

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

1. Introduction

Optical transmission systems employing orthogonal frequency division multiplexing (OFDM) have gained considerable research interest because OFDM can combat fiber chromatic dispersion [1,2] and has the capability to use higher level modulation formats to increase spectral efficiency [3]. An important issue is optical demodulation that can be realized either by means of direct detection (DD) or coherent detection (CD) using a local oscillator [4]. In coherent detection optical-OFDM (CD-OFDM), the signal is transmitted without carrier, thus the Mach-Zehnder modulator (MZM) is biased at power null point, which is the point of most linearity in E-field characteristic. While, in direct detection optical-OFDM (DD-OFDM) a carrier (DC component in equivalent baseband representation) has to be transmitted with the signal, as an OFDM time signal has quasi Gaussian distribution with zero mean. In conventional DD-OFDM, this DC component is generated either by adding a biasing tee or by shifting the operating point of the MZM from the null power point (V_π), i.e. the carrier is electrically generated [5]. This technique is called here as *electrical bias*. In this contribution, we show that the replacement of electrical bias by mean of an *optical bias* improves the transmission performance such that the OFDM signal becomes more robust towards the nonlinear distortions and noise. In this contribution, we show by simulation that by optical biasing we achieve a significant improvement in terms of receiver sensitivity at high signal amplitude both for B2B case as well as in a realistic transmission scenario over 8 spans of 80Km standard single mode fiber (SSMF).

2. DD-OFDM System Setup with Optical Biasing

Fig. 1 shows the DD-OFDM system setup employing optical biasing. The real valued OFDM signal is generated by using a complex conjugate extension for the input to IFFT [6]. The resulting signal drives an external optical MZM which is biased at power null point. Then a bias (DC in baseband simulation) is added in optical domain in order to achieve sufficient carrier power for direct detection.

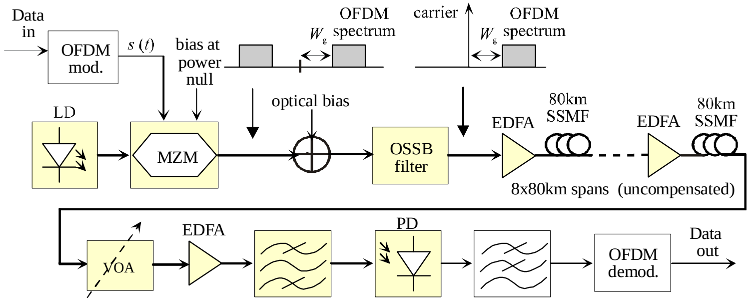

Fig.1: Direct detection optical-OFDM system setup with optical bias.

A single-sideband (SSB) optical filter is used to transmit only one sideband together with the optical carrier. Note that the optical bias can be added after the SSB optical filter which allows of using an optical filter of low order for SSB transmission. The OFDM spectrum (B_{ofdm}) is displaced from the optical carrier by a frequency gap (W_g) to avoid the second-order intermodulation distortion (IMD) due to the square low photodetector (PD). The optical transmission line consists of 8 spans of 80 km of SSMF without dispersion compensation. Span loss is compensated for by means of inline optical amplifiers. For the receiver, a variable optical attenuator (VOA) in front of the optical preamplifier, (erbium doped fiber amplifier, EDFA), allows for optical signal-to-noise ratio (OSNR) tuning. OFDM demodulation is performed including removing of cyclic prefix, serial-to-parallel conversion, FFT, post detection OFDM equalization, symbol de-mapping and parallel-to-serial conversion.

In our investigation we compare the system performance for different biasing technique, namely electrical and optical biasing. In both techniques the bias value is added such that the carrier to single sideband power ratio is equal to one for optimum receiver sensitivity. For data rates of 10.7Gb/s and 42.8Gb/s the bandwidths of the optical filters (Gaussian order 5) are 15GHz and 60GHz respectively. The number of subcarriers is N=512 with QPSK format. The received raw data rates after FEC decoding and removing of cyclic prefix are 10Gb/s and 40Gb/s. The OFDM time signal $s(t)$ is defined here by its standard deviation σ_s normalized by the MZM switching voltage V_π.

3. Optical Biasing

The aim of adding the carrier in optical domain (after MZM) is to minimize the signal distortion due to the MZM nonlinearity. Experimentally, this can be done by splitting the laser signal using an optical splitter, one part is used as an optical carrier for modulation in the MZM and the other part is combined (after delay compensation) with the output signal from MZM using an optical coupler. An optical attenuator can be used to adjust the carrier to single sideband power ratio. For electrical bias the distortion can be seen in the example given in fig.2. In fig.2 (a) a bipolar sinusoidal driving signal is considered as an example modulation signal and fig.2 (b) shows the distortion on the E-field signal after MZM with electrical bias. Note that, the negative part of the signal will be inverted (distorted) after the photodiode in any case. In fig.2 (c) the distortion on the E-field signal is minimized with optical biasing because the MZM is biased at the most linear power null point. This is confirmed in fig. 3, where the transmitted optical OFDM spectra (PSD) before the SSB optical filter, for 42.8Gb/s and σ_s/V_π=0.3, are shown comparing the two different techniques for biasing. Obviously, optical biasing (right) results in low distortion. Thus we conclude that employing optical biasing; the signal distortion can be reduced significantly resulting in an improved transmission performance. Thus we investigate the impact of using an optical biasing on the receiver sensitivity and compare this with the conventional electrical biasing.

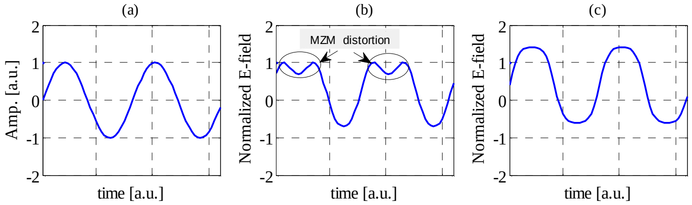

Fig.2: (a) Driving modulation signal, (b) E-field with electrical bias and (c) E-field with optical bias.

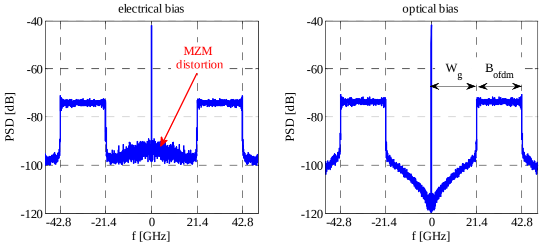

Fig.3: Transmitted OFDM spectra before optical SSB filter with electrical bias (left) and optical bias (right).

4. Simulation Results

Fig.4 shows the results for B2B-transmission without cyclic prefix. It can be shown that, in the case of electrical bias (left), as the signal amplitude increases beyond σ_s/V_π=0.2 the receiver sensitivity degrades due to the system nonlinearities and there is an OSNR penalty of ≈ 3dB for the signal amplitude σ_s/V_π=0.4 compared with σ_s/V_π=0.2 at BER=10^{-3} for both data rates. While in the case of optical biasing (right), same sensitivity performance is achieved even after increasing the signal amplitude from σ_s/V_π=0.2 to σ_s/V_π=0.4 with a negligible OSNR penalty at BER=10^{-3} for both data rates. Fig.5 shows the results for an uncompensated link of 8x80km spans of SSMF. A cyclic prefix of 1/8 of the useful OFDM symbol duration, which increases the OFDM bandwidth B_{ofdm} by a factor of 1.125, is added to each OFDM symbol to compensate for the chromatic dispersion induced inter-symbol interference (ISI) and the input lunch power to each span is 0dBm. It can be shown that, at BER=10^{-3}, in electrical biasing (left), the OSNR penalties are ≈1dB and ≈6dB for $\sigma_s/V_\pi=0.3$ and $\sigma_s/V_\pi=0.4$ respectively compared with $\sigma_s/V_\pi=0.2$. While for optical biasing (right) no OSNR penalty for $\sigma_s/V_\pi=0.3$ and only ≈1dB penalty for $\sigma_s/V_\pi=0.4$ compared with $\sigma_s/V_\pi=0.2$ at BER =10^{-3} for both data rates.

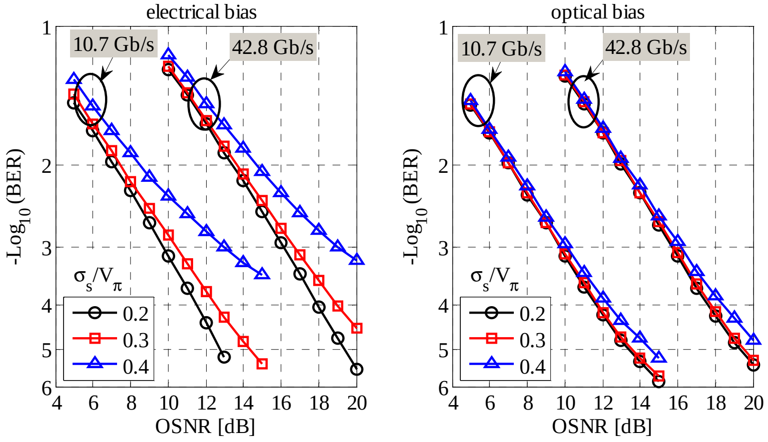

Fig.4: Receiver sensitivity for B2B transmission with electrical biasing (left) and optical biasing (right).

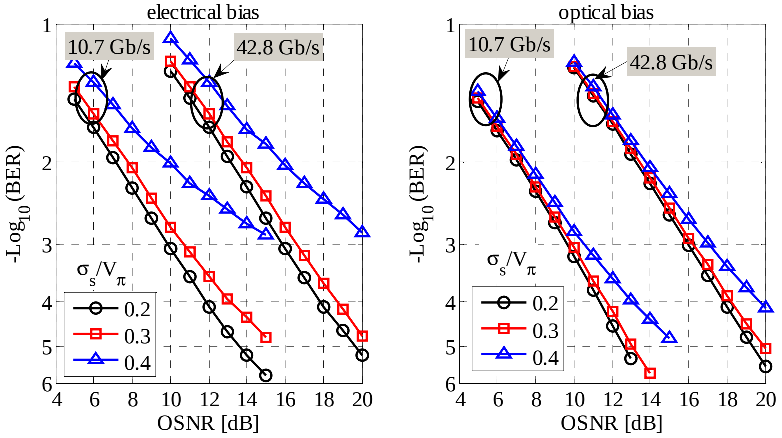

Fig.5: Receiver sensitivity after 8x80km spans of SSMF transmission with electrical biasing (left) and optical biasing (right).

5. Conclusions

A possibility of minimizing the MZM nonlinearity effect for DD-OFDM transmission is studied. Replacement of the electrical biasing by an optical biasing allows the undistorted amplitude of the transmitted signal to be increased and this in turn increases the robustness towards noise, like ASE noise and thermal noise of the optical front end. An improvement of ≈3dB in OSNR is obtained at BER =10^{-3} for both 10.7Gb/s and 42.8Gb/s for $\sigma_s/V_\pi=0.4$ after 640km transmission of an uncompensated SSMF compared with electrical biasing.

6. References

[1] A. J. Lowery and J. Armstrong, "Orthogonal-frequency-division multiplexing for dispersion compensation of long-haul optical system," OPTICS EXPRESS, Vol. 14, March 2006.

[2] Y. Tang, X. Yi, W. Shieh and R. Evans, "Optimum Design for Coherent Optical OFDM Transmitter," Optical Fiber Comm. Conf. (OFC 2006), Paper JThA47.

[3] Z. Jia, J. Yu, D. Qian, G. Ellinas, G. K. Chang, "Experimental demonstration for Delivering 1-Gb/s OFDM signals over 80-km SSMF in 40-GHz Radio-over-Fiber Access Systems," Optical Fiber Comm. Conf. (OFC2008), paper JWA108.

[4] W. Rosenkranz, J. Leibrich, M. Serbay and A. Ali, "Orthogonal Frequency Division Multiplexing (OFDM) and other Advanced Options to achieve 100Gb/s Ethernet Transmission," ICTON 2007, 01.-05. July 2007, Rome, Italy, Vol. 1, Mo.B1.2, pp. 12-15.

[5] A. Ali, J. Leibrich and W. Rosenkranz, "Spectral Efficiency and Receiver Sensitivity in Direct Detection Optical-OFDM" OFC 2009, paper OMT7.

[6] A. Ali, J. Leibrich and W. Rosenkranz, "Impact of Nonlinearities on Optical OFDM with Direct Detection" ECOC 2007, Paper P095.