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*Published in:*  
Proceedings of 2019 IEEE Photonics Conference

*Link to article, DOI:*  
[10.1109/IPCon.2019.8908278](https://doi.org/10.1109/IPCon.2019.8908278)

*Publication date:*  
2019

*Document Version*  
Peer reviewed version

[Link back to DTU Orbit](#)

*Citation (APA):*  
Magalhaes Ranzini, S., Da Ros, F., & Zibar, D. (2019). Joint low-complexity opto-electronic chromatic dispersion compensation for short-reach transmission. In *Proceedings of 2019 IEEE Photonics Conference* Article 8908278 IEEE. <https://doi.org/10.1109/IPCon.2019.8908278>

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# Joint low-complexity opto-electronic chromatic dispersion compensation for short-reach transmission

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**Abstract**— A low complexity solution to mitigate chromatic dispersion is proposed for short-reach communications. The technique relies on sharing complexity between optical and electronic domain and shows gains in terms of required receiver SNR for up to 20-km fiber transmission.

**Keywords**— Chromatic dispersion, optical equalization, electronic equalization, neural network

## I. INTRODUCTION

The rapid evolution of cloud base services is requiring faster and low power solutions for short reach communications. Coherent and direct detection receivers are both potential techniques in the scenario of high bitrates and short-reach links [1,2]. While coherent detection can unlock the huge potential provided by algorithms using digital signal processing (DSP), strategies to reduce production cost, form factor and latency are challenges that need to be overcome [1]. Direct detection receivers are a promising alternative, but chromatic dispersion (CD) is a severe issue for inter-data-center and extended range inter-data-center links. Solutions to mitigate it using DSP are presented in literature [3-5], but they suffer from high complexity. Optical domain alternatives such as dispersion compensation fiber and fiber Bragg grating can also be used, but these solutions are not easily tunable in link length, induce high signal loss and latency and require a large footprint.

Here, we propose a solution based on sharing the complexity between optical and electronic/digital domains. A low complexity tunable CD compensation in the optical domain is performed using a technique based on spectral decomposition (SD) and spectral composition (SC). A further stage of equalization in electronic/digital domain is applied by using a neural network (NN) to mitigate residual distortions. By combining processing in both domains, the total complexity can be reduced.

## II. SPECTRAL DECOMPOSITION/COMPOSITION (SD/SC) FOR CHROMATIC DISPERSION MITIGATION

SD is a technique in which the signal is sliced into narrow frequency sub-bands. The basic building block for this process is a phase-tunable Mach-Zehnder delay interferometer (MZDI), which is highlighted in orange dashed-lines in the inset (a) of Fig. 1. Each block splits the signal into two sub-bands and by cascading the basic structure with optimized delay and phase, the signal can be split into increasingly narrow slices. In other words, the number of sub-bands are increasing as the number of stages increases. Fig. 1 inset (a) shows the values of the delay, in samples, and of the phase for a 2-stage SD (4 slices). After SD of the input signal, a group delay ( $Dly_N$ ) and phase distortion ( $\varphi_N$ ) can be applied to each sub-band in order to mitigate the CD. In order to regroup the sub-bands, the same structure of MZDI (light blue dashed-lines in the inset (a) of Fig. 1) can be used as an inverse operation of SD, namely spectrum composition (SC). If no compensation is applied between SD and SC, a perfect reconstruction of the signal is obtained [6].

## III. NEURAL NETWORK AND TRAINING PROCESS

Fig. 1 inset (b) shows the topology of the NN used in this work. It is a two-layer NN with L neurons in the hidden layer and 32 neurons in the output layer. A hyperbolic tangent function was used as activation for the hidden layer, while a linear function was used in the output layer. A block of 32 samples (4 symbols) is applied in the NN's input per time, without overlap.

The weights of NN, group delay and phase of CD mitigation of SD/SC were jointly trained using stochastic gradient descent optimization with adaptive moment estimation. The loss function considered was the cross-entropy between the transmitted and received bits. During an entire simulation ( $2^{18}$  symbols) all the trainable variables were kept constant and only updated when the next simulation started. 600 iterations were used to train all the variables and they were updated at the same time.

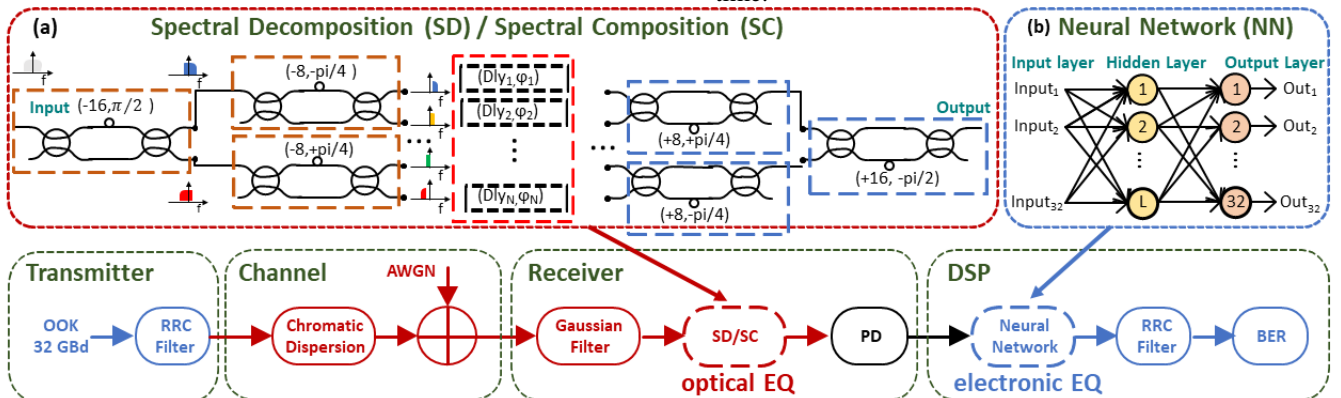


Fig. 1. Simulation setup: SD/CD (inset (a)) and NN-based equalization (inset (b)) are either considered or by-passed depending on the configuration under test.

The training process was applied for each signal-to-noise ratio (SNR) and fiber length. This process was repeated 5 times in order to measure the statistical relevance of the results.

#### IV. SIMULATION SETUP

Fig.1 shows the simulation setup used to validate the hybrid optical/electronic equalization of CD. At the transmitter, an on-off keying (OOK) 32-GBd signal was generated with  $2^{18}$  symbols, up-sampled to 8 samples per symbol and filtered by a root-raised cosine (RRC) filter (roll-off=0.1). The signal was converted to optical domain by assuming an ideal linear transformation. CD and additive white Gaussian noise (AWGN) were added to the signal (channel emulation). The noise variance and CD value were swept to meet the target SNR and distance. At the receiver, a second-order Gaussian filter (40-GHz bandwidth) reduced the noise-to-noise beating in the photodetector (PD). SD/SC were applied to optically mitigate the CD. The PD was considered ideal and the NN was applied as a nonlinear equalizer of the residual CD. The equalized signal was again filtered by a RRC filter and down-sampled to 1 sample per symbol. Finally, hard decision was performed followed by bit error rate (BER) counting.

#### V. RESULTS

Fig. 2 shows the simulation results for the 20-km fiber transmission ( $D= 16.4$  ps/nm·km). The 0-km performance with no equalization is considered as reference and the KP4 forward error correction (FEC), with a BER threshold of  $2.26 \times 10^{-4}$ , is chosen as performance target [7]. Five receiver structures were analyzed. When applying no equalization for 20-km transmission, the CD is a critical impairment and no information can be recovered. By considering only NN-based equalization (16 neurons), the performance is only slightly improved, but they are still far from reaching a BER below the KP4 threshold with up to 20 dB of SNR. This might be explained by the signal dependent variances due to beat-noise [8]. Alternatively, a 2-stage SD/SC can be considered. The optical CD compensation provides significant improvement and presents a better equalization process compared to NN. This is because in the optical domain, the full phase information is still available to the equalizer. Nonetheless, approximated 3 dB of penalty at KP4 FEC, in comparison with the B2B transmission, were observed. The penalty can be significantly reduced by moving to a 4 stage SD/CD scheme at the cost of increased loss and footprint. Alternatively, by combining a 2-stage SD/SC (optical equalizer) and the NN (electronic equalizer), the performance of this hybrid equalizer approaches the 4-stage SD/SC but with a reduced footprint.

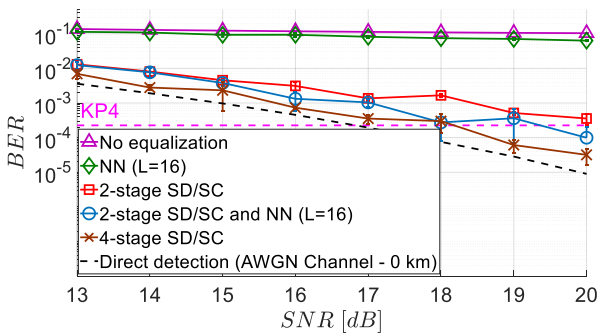


Fig. 2. Simulation results for a 20 km of fiber transmission.

Fig. 3 shows the SNR penalty calculated at the KP4 FEC threshold for all different receiver configurations introduced in Fig. 2, and transmission distances up to 20 km. The penalty is calculated with respect to the B2B reference with no equalization used. Six different scenarios were analyzed. A 1-stage SD/SC (2 slices) shows results with significant penalties reaching 3 dB already for 11 km. Very similar performance are observed for a NN-base equalization ( $L=16$ ). By using both equalizers together the results are only slightly improved. The limited gain might be caused by the slices still being too broad for a fine CD mitigation. Alternatively, a 2-stage SD/SC (4 slices) can be applied. The penalty in this case increases more slowly with the distance but reaches 3 dB at 17 km. By adding a NN-base equalization to the 2-stage SD/SC, an improvement up to 20 km with reduced penalty is achieved. A similar behavior could be achieved with the more complex 4-stage SD/SC.

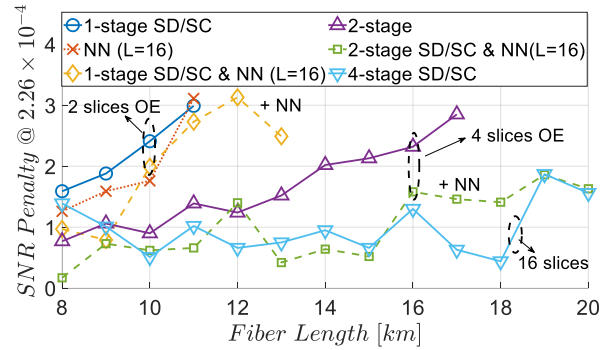


Fig. 3. Simulation results for the SNR penalty calculated at FEC KP4.

#### VI. CONCLUSION

We proposed an optical/electronic equalization for short reach applications where the complexity to mitigate CD is shared between optical and electronic domain. We showed that 2-stage SD/SC together with a NN with 16 neurons in the hidden layer has a similar performance as a 4-stage SD/SC, but with less complexity in the overall system.

#### ACKNOWLEDGMENT

We thank Dr. Henning Bülow from Nokia Bell Labs for stimulating discussions. This work is supported by the European Industrial Doctorates (FONTE project, grant no. 766115).

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