# Smart few-mode fiber multiplexer using multiplane light conversion

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**Abstract:** We propose a digital twin using multiplane light conversion and neural networks for a digitally programmable multiplexer for space division multiplexing. The new approach is promising for few-mode fiber communication. © 2023 The Author(s)



## 1. Introduction

Development of fiber optical networks as the backbone of the global infrastructure has driven exponential growth in data demands. Space division multiplexing (SDM) over few-mode fibers (FMF) spatial domain is proposed to enhance optical network capacity limits by orders of magnitude compared to state-of-the-art single mode fibers. Based on multiplane light conversion (MPLC), multiple input beams are converted to the FMF mode domain and launched into the fiber. We use a spatial light modulator (SLM) for the implementation of the MPLC, whose programmability allows us to design the MPLCs behavior digitally and compensate on phase and polarization aberrations during operation [1-4]. Conventionally, phase masks are calculated in advance that carry out a spatial transformation between spatially distributed input spots and coaxial output modes. After calculation, phase masks are either printed on dielectric mirrors or displayed on diffractive optics. This process entails two-fold problems. First, the phase masks are calculated offline and inserted into the experiment later on, where small deviations cause enormous performance reductions. Second, phase mask printing can barely be adapted after fabrication. We propose a data-driven optimization of the displayed phase mask by using machine learning to overcome the hurdles of re-configurability and alignment

## 2. Method

In this paper, we present a method to advance the mode shaping procedure by a smart data-driven online calibration, where the entire MPLC implementation with a SLM is considered as a black box, as shown in Figure 1. By training an NN, we create a digital twin including all misalignments and tolerances of the setup, called Model-NN. Afterwards, the Model-NN is kept static and another NN called Actor-NN is trained controlling the model. As training the model was performed on all-experimental data, it contains knowledge on the system. This is used in the offline training of the Actor-NN to predict the required phase masks for the SLM to perform the desired beam shaping task, i.e. modulating the mode patterns of a FMF.

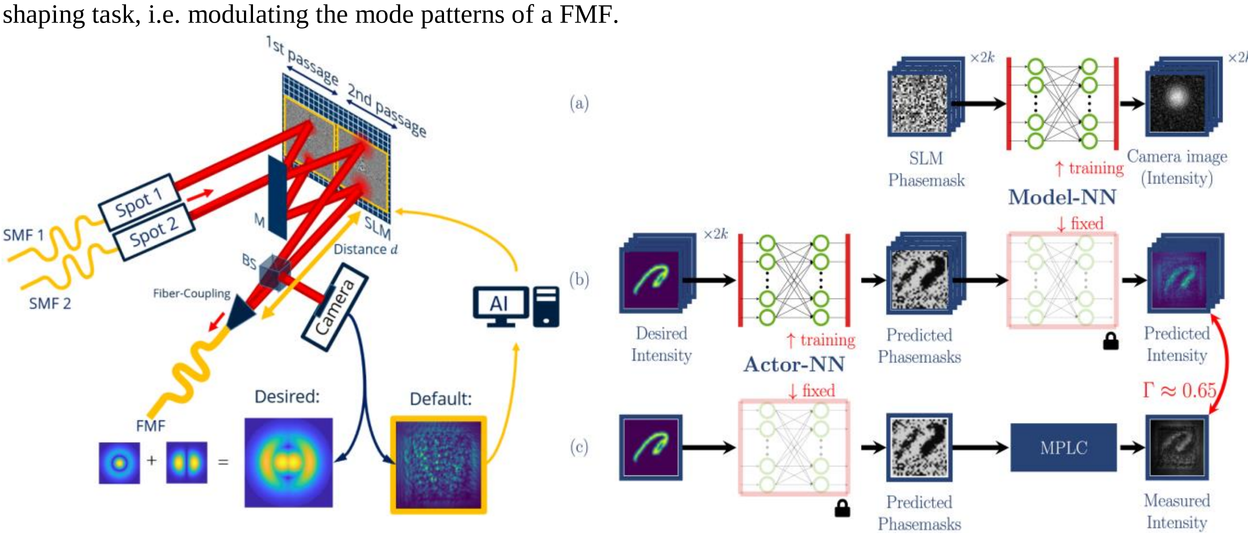


Fig. 1. AI-driven optimization scheme, Left: Optical MPLC, Right: Scheme of neural networks for training and control of the digital twin

## 3. Results

After training of the entire Actor-Model structure, the Actor-NN is frozen and is used to generate phase masks for the experiment. The phase masks provided by the Actor-NN are displayed on the SLM to run the MPLC. In Figure 3 (right column), three camera images capturing the MPLC output are shown. The images are taken after the setup was calibrated with the approach introduced. We achieve a correlation between the ground truth and the Model-NNs prediction of C = 0.7. For the measured intensity we achieve a correlation of C = 0.65 compared to the Model-NNs prediction and C = 0.6 to the ground truth.

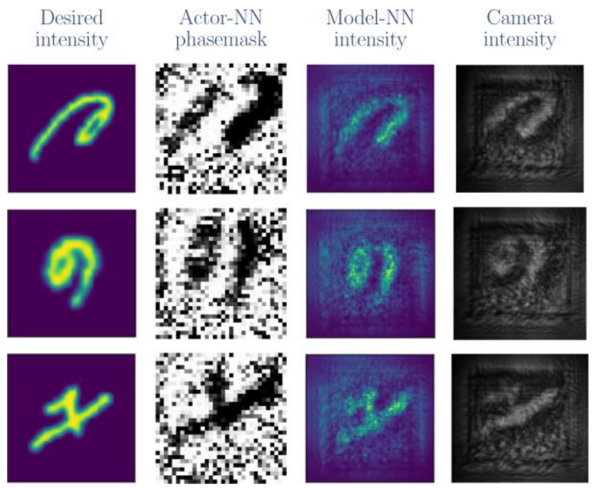


Fig. 2. Results from the Actor-Model approach. Left column: Ground truth,
Middle left: Actor-NNs phase mask prediction, Middle right: Model NNs intensity prediction, Right column: experimental results [6]

## 4. Conclusion

We have demonstrated an intelligent approach to calibrate an MPLC device using experimental data. Although we treat the entire light shaping system as black box, delicate knowledge about the experimental behavior is gained by using machine learning algorithms with C = 0.82. Here, we have shown that the Actor-Model approach is feasible for online calibration of an all-optical mode multiplexer based on MPLC. In contrast to an offline calculation of SLM phase masks, our approach does not suffer from mismatches between algorithm and experiment reducing the alignment effort dramatically. By digitally sampling and control of the MPLC behavior with NN, we improved the SLM beam-shaping quality without suffering from the SLM refresh rate limitations, depending on the available filling factor and spatial resolution. The adaptability of the SLM as a digital optical device allows further re-calibration during operation [4-6]. Due to the all-optical implementation, transmission and multiplexing of delicate quantum states for QKD-based physical layer security in fiber communication is proposed. This is particularly beneficial for the advancement of SDM networks [7-8].

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