

**Title:**

Machine learning method to measure the transmission matrix of a multimode optical fiber without reference beam for 3D beam tailoring

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In recent years, multimode fibers (MMF) have received renewed interest in line with the development of output wavefront shaping devices. The incident wavefront is adjusted to manage the degrees of freedom of the light propagated through the MMF, opening new opportunities to enhance capabilities in various applications such as optical communications or endoscopic imaging systems. The transmission matrix (TM) measurement methods that use a reference wave offer a high potential enabling 3D-shaping through MMFs. One of the ongoing challenges is to recover this TM from only a set of pure-intensity measurements at the output fiber, i.e. without any reference beam. However, in most of the published works, the MMF model built by optimization from the data set can only predict output intensities.

In this communication, we propose a novel reference-less method designed to predict the emitted complex field. It uses a machine-learning based optimization by mini-batch gradient descent. We first validated our method by performing simulations with MMFs propagating up to  $N \sim 700$  LP modes. A TM of  $16384 \times 584$  elements was learned with a data set of  $\sim 6000$  input phases/output intensities and 50 epochs. Only ten additional intensity measurements in a second plane were required to remove the residual phase error between TM rows. Pearson correlation coefficients reached 99.95% at the MMF output, and 98% at the second plane, showing that our method is able to predict any output complex field. The high accuracy of the prediction was also confirmed experimentally paving the way for 3D beam shaping through MMFs.