# Momentum Space Controlled Flexible Spatial Light Modulator for Optical Wireless Communication

**Zizheng Cao[1], Xinda Yan[1], Yiwen Zhang[2,]*, Chao Li[3], Juhao Li[4], Chia Wei Hsu[2,]*, Ton Koonen[1]**
*[1]Eindhoven University of Technology, 5600MB Eindhoven, the Netherlands*
*[2]University of Southern California, Los Angeles, California, USA*
*[3]Peng Cheng Laboratory, Shenzhen 518055, China*
*[4]State Key Laboratory of Advanced Optical Communication Systems and Networks, Peking University, Beijing 100871, China*
*Author e-mail address: yzhang67@usc.edu, cwhsu@usc.edu*

**Abstract:** Traditional spatial light modulators (SLMs) shape an incident wavefront pixel-by-pixel. This talk explores a new class of SLMs named momentum space controlled spatial light modulators (MSC-SLMs). An optical-wireless-communication link enabled by MSC-SLMs is demonstrated. 

## 1. Introduction

Shaping the wavefront through amplitude and phase modulations is a key function for many applications such as display, adaptive optics, laser manufacturing, and so on. Spatial light modulators (SLMs) are the key devices for wavefront shaping. As one of the most popular applications, the display industry provides a mature and low-cost solution for wavefront shaping using liquid crystal SLMs (also referred to as liquid crystal display, LCD). Traditional SLMs shape an incident wavefront pixel-by-pixel. To allow enough layout space for the control electrodes of each pixel, the spacing between two adjacent pixels cannot be further reduced, resulting in grating lobes and limited resolutions. To overcome such a limit, here we propose a new class of SLMs, named momentum space controlled spatial light modulators (MSC-SLMs). In an MSC-SLM, an incident wavefront is decomposed to multiple orthogonal modes in momentum space (k-space). Rather than controlling each pixel in real space, the phase and amplitude control can be applied to each mode in the momentum space. Then the desired wavefront shaping can be synthesized in real space. MSC-SLMs allow very different design frameworks compared to traditional SLMs. The resolution of MSC-SLMs is not directly limited to pixel spacing. We also propose a simple and powerful kind of MSC-SLMs using multimode fiber (MMF). The spatial and spectral properties of the proposed MSC-SLMs are investigated and the novel random-certain control mechanism is also discussed. Using the proposed MSC-SLM, a beam-steerable 10 Gbps OWC link is demonstrated [1]. In this talk, we review our recent work reported in [1] and the following extended work in this field.

## 2. Principle of the MSC-SLM

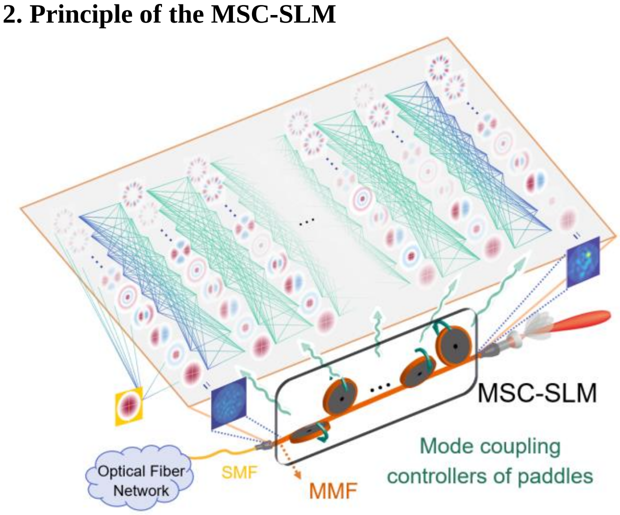


Figure 1 Principle of the proposed momentum space controlled spatial light modulators.

The proposed MSC-SLM includes an MMF and multiple mode-coupling controllers (MCCs) as shown in Fig. 1. Multiple orthogonal spatial modes are propagating in the MMF. The wavefront of an incident optical signal will be decomposed into modes of the MMF. The MMF serves as a real space to momentum space converter. Index imperfections and geometrical shape changes induced by bending, twisting, and pressing introduce coupling from one mode to another. Such mode coupling effect is traditionally not desired since it introduces inter-mode interference and random modal dispersion. These effects can be compensated using mode diversity reception combining digial signal post-processing [2], which relys on sophiticated hardware. The optical approach is proposed for MCS-SLM [1]. The basic ideas are summarized below.

*Mode coupling as a tool*. If the mode coupling effect is controllable, it can be used to shape the wavefront of the optical signal emerging from an MMF. Starting from this thought, we introduce MSC-SLM exploiting the mode coupling effect rather than avoiding it. As shown in Fig. 1, several paddles are employed as the MMCs in the MSC-SLM to realize bending and twisting along the MMF. The MMCs use the similar mechanical schemes as the ones used for polarization controllers, but with the single-mode fiber (SMF) replaced by an MMF for MMCs.

## 3. Experimental setup and initial results of MSC-SLM

*MMF-based MSC-SLM*. A standard OM2 50/125-mm graded-index MMF is connected to an SMF and is looped around nine paddles as shown in Fig. 1. The paddles create bending/twisting-induced birefringence and mode coupling for spatial light modulation of the incident optical signals. The proposed scheme of paddles has a gentler bending with less than 1 dB extra loss, comparable to the one reported in [3]. Each paddle can create an individual degree of freedom that acts like a pixel in a real space controlled SLM. Since the optical signal is propagating all in the fibers, there is no fiber to free-space or fiber to chip coupling loss and diffraction loss. After the MSC-SLM, the optical signal is projected to free space via a triplet collimator and a plano-convex lens. The paddles are then tuned in a feedback loop to modulate the output wavefront of the optical signal.

*Spatial properties of beam-steering using the MSC-SLM*. Using the proposed MSC-SLM, the beam-steering/forming is realized in a 14-cm-diameter region after 80-cm propagation, corresponding to the steering range of 10 degrees [1]. As reported in Fig. 1(b) of the reference [1], the typical output patterns before and after the optimization for different receiver locations are shown.

*Spectral properties of beam-steering using the MSC-SLM*. The measurement setup of the spectral properties of beam-steering using the MSC-SLM is shown in Fig. 2. Passing by a lens and a splitter, 95% of the emitting power from the collimator is transmitted to the receiver end with an 8.9° full divergence angle, while the remaining power is captured by a near-infrared (IR) Charge-coupled Device (CCD) camera in the perpendicular direction. The distance between the collimator and the power meter is 70cm, and the coverage radius of the beam at the receiver plane is 5.4cm. Received beam profiles of 8 ITU C-band channels from C33 (1550.92nm) to C26 (1556.55nm) with an interval of around 0.8nm are shown in Fig. 3. While the emited optical power at the transmitter end is 7.74dBm, the corresponding received optical power from Fig. 2a to Fig. 2h are -10.45dBm, -13.98dBm, -15.53dBm, -13.99dBm, -15.23dBm, -14.55dBm, -17.44dBm and -20.45dBm, respectively.

*Optical wireless communication system*. As reported in [1], using the MSC-SLM transmitter, an optical wireless

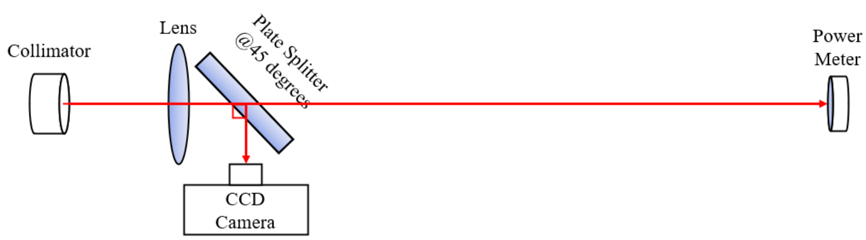


Figure 2. Experiment setup for observing the far-field beam profile and measuring the received optical power.

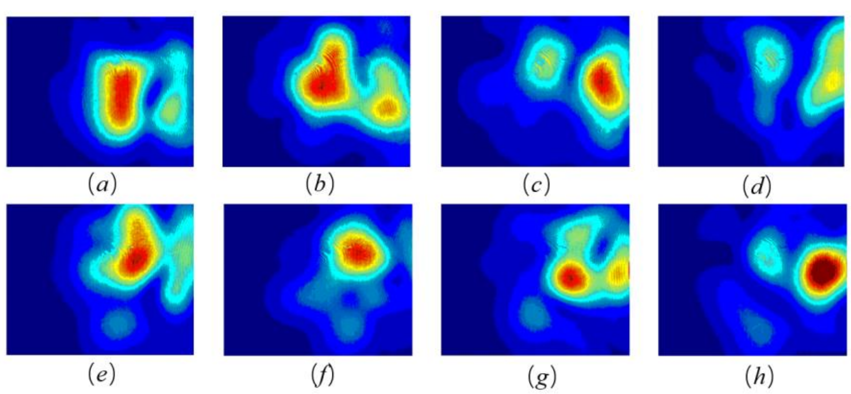


Figure 3. Measured beam profile of ITU C-band channels from C33 (1550.92nm) to C26 (1556.55nm).

communication (OWC) link is established. The data transmission with 10-Gb/s on off keying signal and 10-degree steering angle is experimentally demonstrated. The OWC receiver is placed 80 cm away from the MSC-SLM transmitter. Without the optimization by spatial light modulation, the received signal cannot be demodulated; after optimizing the MSC-SLM transmitter, the received signal can be demodulated, with the 7% forward error correction (FEC) limit of BER $=3.8\times10^{-3}$ reached at -10 dBm received power. A simple, low-cost, and effective beam-steerable OWC system empowered by the MSC-SLM is validated.

## 4. Conclusion

In this talk, we explore a new class of SLMs named momentum space controlled spatial light modulators (MSC-SLMs). Rather than controlling each pixel in real space as traditional SLMs, the phase and amplitude control can be applied to each mode in the momentum space. Then the desired wavefront can be synthesized in real space. The resolution of MSC-SLMs is not directly limited to pixel spacing. We also propose a simple and powerful kind of MSC-SLMs using MMF. Its spatial and spectral properties of beam-steering are discussed. A beam-steerable optical-wireless-communication link is demonstrated using the MSC-SLM transmitter.

## 5. Reference

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