Large Aperture and Wide Field of View Meta-Receiver for Free Space Optical Communications

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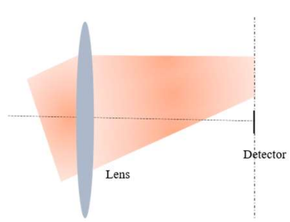
Abstract: We present large aperture optical meta-receiver design to capture ±5° incident angles on single photodetector by using two metalenses and one off-the-shelf aspheric lens to eliminate the impact of pointing jitter in free-space optical communications.

1. Introduction

Conventional free-space optical (FSO) receivers offer limited field of view (FOV). As a result, small deviation from normal incident angle would cause the beam to miss the detector as shown in Fig. 1(a). Complex Pointing, Tracking and Acquisition (PAT) mechanism is needed to keep the receiver aligned with the transmitter to maintain optical communication link continuously. Even with PAT, any unavoidable short-term vibration termed as pointing jitter degrades system's BER [1]. A wide FOV receiver can resolve this problem [2]. In this paper, we present large aperture and scalable receiver architecture that can capture wide range of incidence angles on a single point detector by using an off the shelf aspheric lens and two metalens customized for the selected aspheric lens. To achieve this goal we create a phase profile for the aperture metalens and obtained the phase profile of the second metalens numerically by implementing generalized Snell's Law [3]. Our proof-of-concept design has 9mm aperture and shows that it can capture ±5° incident angle on a single detector sitting on the optical axis. Although, several wide FOV metalens designs are discussed in literature [4,5], their design goal is imaging applications by using arrays of detectors, and hence they are not suitable for communication systems that use a single detector to capture all the different incident angles. Due to wide FOV, the proposed receiver can reduce pointing jitter problem of FSO communication, Moreover, the receivers can be stacked vertically to increase the input aperture size to capture more light.

2. Working Principle

The proposed system consists of two metalenses (ML1 and ML2) and one off-the-shelf aspheric lens [2] in a tandem arrangement as shown in Fig. 1(b). For simplicity we present our discussion for 2D system, but the idea can be easily extended to 3D system. The 1D phase profile for metalens 1(ML1) is $\emptyset_1(y) = -k_0[\sqrt{(y-my)^2+f^2} - f]/(1-m)$. k_0 is the free space wavenumber, f is the focal length of first metalens and m is the beam compression factor. The phase profile ensures that for ray normally incident on ML1 at a spatial coordinate y will hit the ML2 at coordinate $m{\cdot}y$ [6]. The advantage of this phase profile is that the beam size on ML2 can be determined independent of focal length, f of ML1. Another advantage is that the beam walk-off on the surface of ML2 is independent of beam size and depends only on f and incident angle, α_{inc}. With carefully chosen m, ML1 spatially separate the beam of different incident angles on the plane of ML2. The phase profile of ML2 is chosen such that the transmitted beam will get parallel to the optical axis. If we look at ray picture in Fig. 2(a), each ray (with height y) of input beam will incident on ML2 at different incident angle ($\alpha(y)$) depending on system parameters (aperture size, f, and α_{inc}). Upon the application of Generalized Snell's Law [3] , the phase profile needed for ML2 to make the transmitted ray parallel is $\emptyset_2(y) = -k_0 \int \sin(\alpha_y)\, dy$. The integration needs to be done numerically as for large aperture there will be significant variation of $\alpha(y)$ across the beam. The metalenses can be built with any suitable meta-building block (for example, like the one presented in [2]). Finally, the aspheric lens focuses all the parallel beams emerging from ML2 to the single point on optical axis.



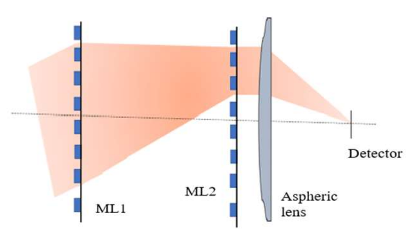
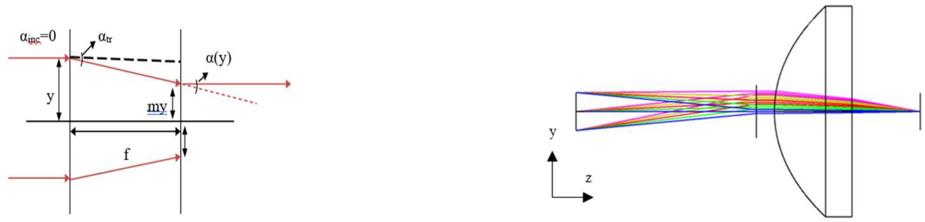


Fig. 1 Off-normal incident beam on (a) conventional receiver and (b) proposed receiver

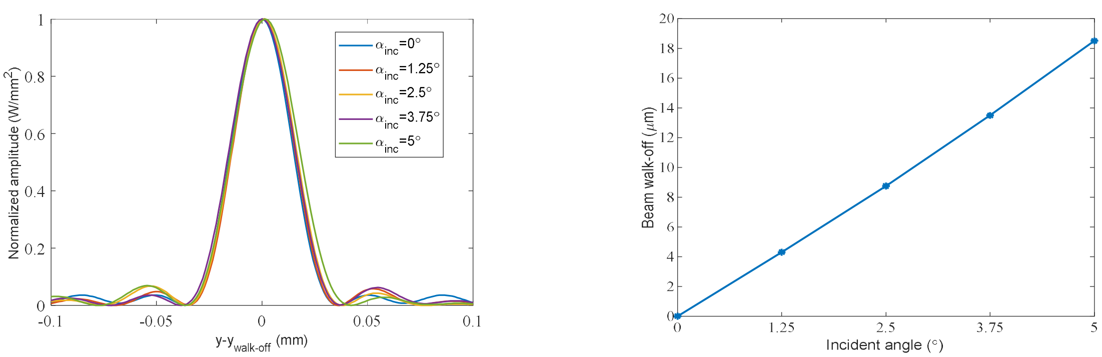


(a) (b)

Fig. 2 (a) Ray diagram showing design parameters, (b) Ray diagram for the designed system

3. Results

As a proof of concept, we designed a system with input aperture, *a=9mm* and *f=50mm.* We have chosen *m=1/10* that will provide enough beam compression so that the incident beam on ML2 with incident angles *0°,1.25°, 2.5°, 3.75°* and 5° are spatially separated. Then, the phase profile of each segment of ML2 can be obtained only for one specific incident angle. Smaller value of *m* allows more segmentation of ML2, but for off-normal incident angle there may be ray crossing before or on ML2. This will invalidate the proposed method of phase profile determination of ML2. Analysis on the designed system is done using Zemax OpticStudio. For aspheric lens, we use an off-the-shelf aspheric lens from Edmund Optics. Ray diagram in Fig.2(b) shows that different incident angles are getting focused to the same point on optical axis. Physical optics propagation analysis is carried out with *9mm* top hat beam as input beam. The beam profile on detector is shown in Fig.3(a). In the figure, beam coordinate is shown as difference between absolute coordinate (y) and beam walk of coordinate ($y_{walk\text{-}off}$). The beam walk-off for different incident angles are shown in Fig.3(b). For *5°* incident angle we have maximum beam walk-off of around *18µm*. The FWHM beam width on the detector is less than *40µm* for all the incident angles. Once the phase profile is generated actual metalens blocks are designed by Comsol Multiphysics [2] by using silicon nanopillars with varying diameters and fixed period.



(a) (b)

Fig. 3(a) Beam Profile at the detector, the beam amplitudes are normalized to 1, (b) Beam walk- off for different incident angle

4. Conclusion

In summary, we have presented a receiver architecture design with large aperture for collecting optical beam from broad range of incident angles with a single detector. In real world, aperture size of such system will be restricted by the fabrication limitation of large area metalens. In that case, vertical stacking of many small aperture metalenses may be implemented to realize broad aperture. Optimization of such compound system is one of the goals of our future research.

5. References

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