URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Robust Vector Beams for Propagation through Random Media

Priyanka Lochab*[(1)], P. Senthilkumaran [(1)], and Kedar Khare [(1)]
(1) Department of Physics, Indian Institute of Technology Delhi, India-110016
Email: priyanka.lochab@gmail.com; psenthil@physics.iitd.ac.in; kedark@physics.iitd.ac.in;

The propagation dynamics of a laser beam strongly depend on its initial structure (like its amplitude and phase profile, polarization and coherence properties etc.) and on the type of medium through which it propagates. In random media, like the Earth's atmosphere, turbulence in the form of spatial refractive-index fluctuations give rise to phase perturbations in the laser beam. These phase perturbations lead to various undesirable effects in the beam like intensity scintillation, beam broadening, beam wandering, decrease in spatial coherence and loss of optical power. These effects make the beam unusable for any practical application and additional corrective means like adaptive optics are required. Therefore, designing laser beams which are inherently resistant to phase perturbations and are able to sustain a robust intensity profile with minimal corrections is very important.

Few studies have shown that inhomogeneously polarized vector beams have lesser scintillation on propagation through turbulence. The general expression for a vector beam is given as:

$$\vec{E}(\boldsymbol{r},z,t) = [E_1(\boldsymbol{r},z)\widehat{e_1} + E_2(\boldsymbol{r},z)\widehat{e_2}]e^{i(kz-wt)} \quad (1)$$

where $\widehat{e_1}$ and $\widehat{e_2}$ are two orthogonal polarizations and **r** gives transverse coordinates. The two polarization components in inhomogeneously polarized vector beams have different amplitude and phase structure i.e. $E_1 \neq E_2$. Orthogonal polarizations do not interfere on propagation and the total intensity of the vector beam is equal to the sum of the intensities of the individual polarizations. However, it has been recently shown by us [1] that all inhomogeneously polarized beams are not equally robust or useful for minimizing scintillation. In fact, in order to design a robust vector beam, there is an optimal methodology [1] for choosing beam profiles E_1 and E_2. Clearly if the speckle patterns corresponding to the two polarizations are positively correlated then on adding them, there is no gain in terms of reducing beam fluctuations. However, if the speckles are negatively correlated, the locations of intensity maxima for one polarization component will coincide with the location of intensity minima of the orthogonal polarization component. Therefore, addition of these speckle patterns will reduce the fluctuations in the total intensity of the beam. Hence, E_1 and E_2 profiles should be chosen such that they give rise to negatively correlated speckles on propagation. Such a beam will have significantly improved signal-to-noise ratio (SNR).

A simple construction of such beam is further shown using orbital angular momentum (OAM) diversity [2]. Here the two polarizations ($\widehat{e_1}$ and $\widehat{e_2}$) contain different OAM states, namely *l=0* and *l=1* which on collinear propagation through turbulence give rise to highly negatively correlated speckles. The diffraction patterns of these two OAM states form a 2D Hilbert transform pair [3], and so their speckles show this complementary nature and high negative correlation. This beam is experimentally realized using a spatial light modulator and is passed through random phase screens. The measured SNR values show significant improvement as compared to a Gaussian scalar beam. The polarization structure of this beam is also unique as it hosts a C-point polarization singularity. Further comparative experimental studies of different types of vector beams like radially and azimuthally polarized beams is also done and it is shown that positively correlated or uncorrelated speckle patterns are not helpful in reducing intensity fluctuations in the vector beam. In conclusion, a generic guideline for designing vector beams that can maintain a robust intensity on passing through random medium is provided. This study will be useful in a number of applications which require robust laser beam propagation like laser guided defense systems, free space optical communications, imaging systems etc.

1. P. Lochab, P. Senthilkumaran, and K. Khare, "Designer vector beams maintaining a robust intensity profile on propagation through turbulence," *Phys. Rev. A*, **98**, August 2018, pp. 023831, doi:10.1103/PhysRevA.98.023831.

2. P. Lochab, P. Senthilkumaran, and K. Khare, "Robust laser beam engineering using polarization and angular momentum diversity," *Opt. Express*, **25**, July 2017, pp. 17524-17529, doi:10.1364/OE.25.017524.

3. K. Khare, "Complex signal representation, Mandel's theorem, and spiral phase quadrature transform," *Appl. Opt.* **47**, August 2008, pp. E8-E12, doi:10.1364/AO.47.0000E8.