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Towards experimental validation of full-wave precompensation for laser telecommunications

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Abstract: We designed an optical bench to demonstrate full-wave precompensation for laser telecommunications. This technique requires a device performing time reversed waves. We propose and characterize a solution to realize such a function.
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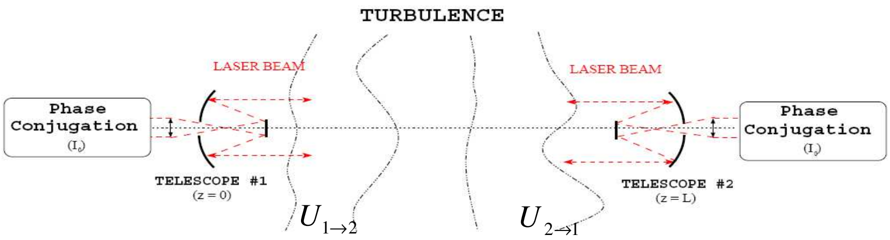
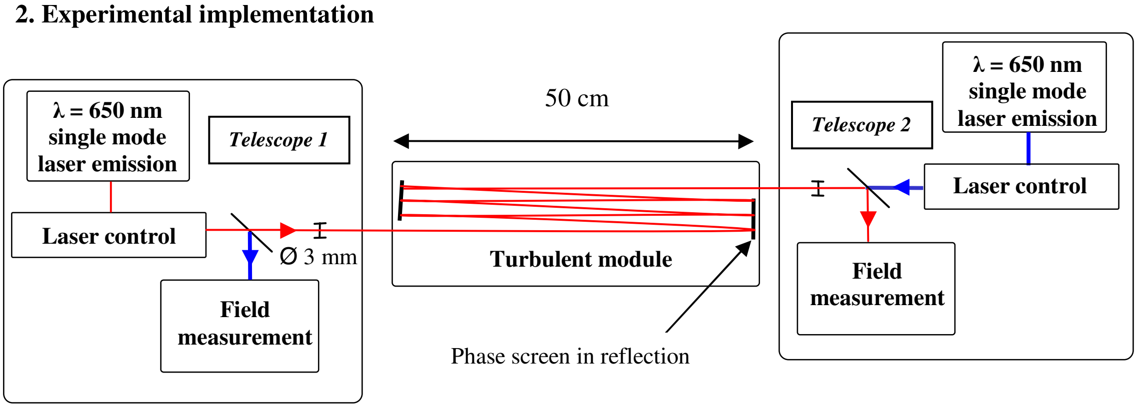
1. Introduction

Terrestrial horizontal laser telecommunications over a several kilometres propagation range are highly disturbed by the dynamic fluctuations of the atmosphere index. Along the propagation, the beam is shifted, spread, and broken up. In conditions of typical turbulences above ground obstacles - $C_n^2 = 10^{-14}$ $m^{-2/3}$ at a thirty-meter altitude - the intensity detected after propagation without any correction in a finite detector varies through the time, and can even be shortly extinguished [1]. To mitigate the atmospheric turbulence, some techniques of precompensation of the emitted light were suggested [2, 3]. Barchers proposed to use counter-propagating beams with iterative correction (see Fig. 1). He demonstrated numerically the efficiency of this concept in weak turbulence conditions. Nevertheless, full-wave iterative precompensation may be efficient as well in case of stronger turbulence regime [4].



"Figure 1: Basic concept of the optimal amplitude and phase iterative correction"

2. Experimental implementation



"Figure 2: Experimental implementation"

We develop an experimental set-up to test the full-wave iterative correction in strong perturbation regime and to demonstrate the pertinence of this concept for laser telecommunications (see Fig. 2). Actually, to be representative of a several kilometres propagation range while fitting an optical bench size, all physical parameters are scaled. Phase screen amplitude, propagation distance, wavelength and pupil diameter are chosen in order to ensure phase perturbation and diffraction effects conservation. Three reflections on a phase screen simulate the turbulent volume. After a first propagation, the complex field is measured in the pupil plane receiver. Then a back propagating beam, controlled in order to reproduce the conjugate of this measured field, is emitted from this receiver. The process is applied iteratively. Main difficulties consist in the measurement of the field with strong scintillation and in the control of the complex emitted field.

3. Complex field measurement and control

a. Complex field sensing

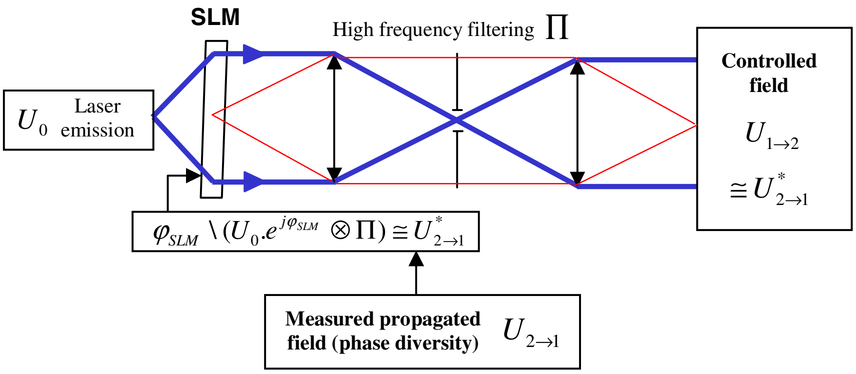
To operate a full-wave iteration, the first issue is to estimate the incoming complex field. The amplitude is easily measured. On the other hand, an estimate of the phase associated to the speckled amplitude induced by turbulence is hardly obtained with usual phase gradient measurement techniques, such as the Shack-Hartmann sensor [5]. Indeed, the reconstruction step requires measurements to be defined in the whole pupil plane. Direct measurement of the phase is therefore better. We chose the phase diversity technique for our lab experiment [6, 7]. The data reduction process, presently slow, could be fastened for real system. An upgraded phase diversity technique has been developed, for which not only the focal plane signal S_1 and a defocused plane signal S_2 have to be registered, but the pupil plane I_3 as well to minimize the J criterion regarding to phase φ we are looking for (Eq. 1). In case of a coherent beam, J denotes:

$$J = |I_1 - S_1|^2 + |I_2 - S_2|^2$$
$$S_1 = \left|FT(\sqrt{I_3} e^{i\varphi})\right|^2, \quad S_2 = \left|FT(\sqrt{I_3} e^{i\varphi+\varphi_d})\right|^2 \tag{1}$$

I_3 here replaces the usual homogeneous pupil P, FT is the Fourier Transform.

b. SLM control for phase conjugation

The conjugate of the random complex field detected in plane 2 has to be emitted from the modulation of a usual homogeneous laser source. The modulation of both phase and amplitude of the initial beam may be performed by a Spatial Light Modulator (SLM) printing a high frequency phase on the laser field followed by low frequency filtering using a pinhole in a 4f assembly (see Fig. 3) [8].



"Figure 3: Experimental control of the field"

c. Experimental results

Measurements with phase diversity technique and phase and amplitude control were independently both experimentally demonstrated. We intend here to show the capability of phase diversity to measure the field when the amplitude is not uniform in the pupil plane and to study the coupling of both techniques, that is our capacity to calibrate the control with respect to the measurement. The result is illustrated using an example. We aimed to reproduce a ring-shaped amplitude associated with a Z_{14} Zernike mode evolving from 0 to 2π as presented on Fig. 4 and 5. φ_{SLM} was processed in order to obtain such a modulation. The control of the field was realized with a SLM (Hamamatsu LCOS-SLM X10468), with 792 x 600 pixels of

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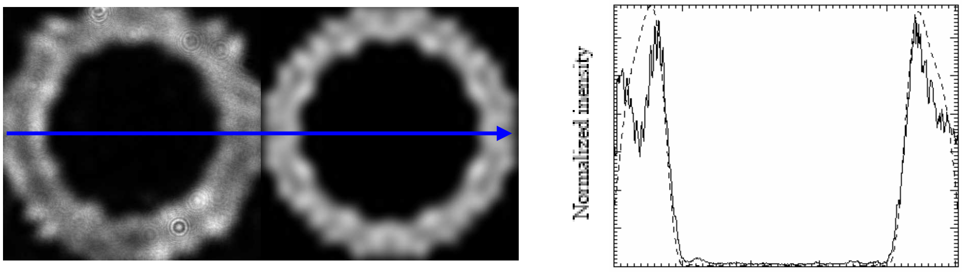
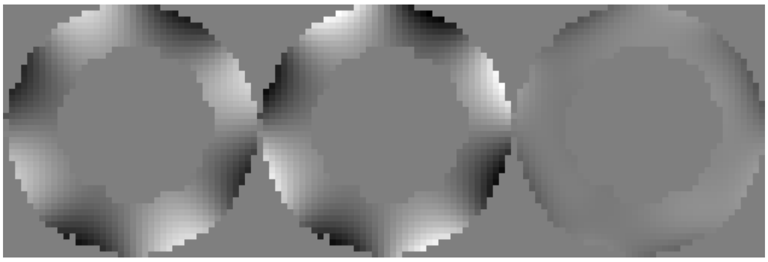
20 µm x 20 µm size. The intensity measurements for phase diversity were performed with a CCD array sensor (Hamamatsu ORCA-AG).



“Figure 4: Experimental (left) and aimed (right) intensity and horizontal sections (— exp. and - - - aimed)”



“Figure 5: Experimental phase (left), aimed phase (centred) and their difference (right)”

We obtain a 0.2 rad rms residual phase to be compared with a 1 rad rms measured phase. The whole residual phase is concentrated at the edge of the pupil due to frequency filtering smoothing effects. However, this edge distortion shall not disturb the precompensation efficiency. Phase diversity has then achieved to measure with excellent precision the phase we aimed through the SLM command and spatial filtering. This proves that the coupling between the SLM control and detection field is effective to perform phase conjugation for full-wave correction.

4. Conclusion

We have proposed a first demonstration of our ability to couple control and measurement of the complex field to perform time reverse waves. Future step will consist in performing this field conjugation to test experimentally the full-wave iterative correction.

5. References

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