1.5 µm all fiber pulsed lidar for wake vortex monitoring

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INTRODUCTION

A new 1.5 µm pulsed Lidar using an all fiber laser source has been developed by ONERA in cooperation with Leosphere , for wake vortex and wind field measurements . The Lidar has been designed for medium range detection (50 to 400 m). This system is based on telecom fiber technology which offers low cost and reliable components. The system has been tested on an airport field and has demonstrated to be well suitable for wake vortex monitoring.

LIDAR ARCHITECTURE

For this new lidar, Onera and Leosphere have put emphasis on three sub systems : a pulsed fiber laser based on a Master Oscillator Power Fiber Amplifier architecture (MOPFA), a compact Brewster circulator, and an user friendly MMI with real time wake vortex monitoring.

The MOPFA architecture of the laser allows to change the pulse duration, repetition rate and shape within a certain range and adapt it to the lidar application. For wake vortex detection, a pulse duration of 250 ns has been chosen as a trade off between velocity resolution and spatial resolution.

Laser

The Master Oscillator Power Fiber Amplifiers (MOPFA) using Erbium-Ytterbium doped fibers are well adapted for 1.5µm high energy pulse generation. The peak power is however limited by Stimulated Brillouin Scattering because of the narrow signal linewidth. To overcome this limitation, large-mode-area (LMA) fibers are required with mode diameters beyond 30 µm. These fibers must also have low core NA to avoid multimode operation and minimize ASE generation. Onera has studied the influence of the MOPFA architecture on the performances[1,2]. We have recently developed a 3 stages all fibered amplifier (Figure 1) with 60 µJ pulses and 250 ns pulse duration. The high peak power (>240 W) requires large core diameters.

The third stage of amplification is built with a 25 µm core fiber which guides up to 6 LP modes groups. Thanks to a proper packaging, the beam quality is still compatible with coherent detection requirements[3] (the beam quality factor M^2 was measured to be close to 1.4). The beam is linearly polarized with a degree of linear polarization better than 98%. Figure 2 shows the beam profile in the focal plane (a) and the polarisation ellipsoid (b).

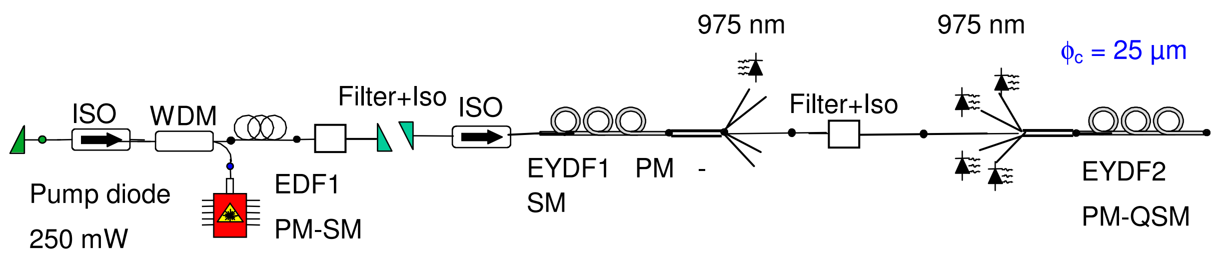

Figure 1 : Set-up of the laser source (ISO : isolator, WDM : 980 nm/1550 nm multiplexer, EDF1 : Erbium doped fiber ; EYDF1 : Erbium-Ytterbium doped fiber ; EYDF2 : Erbium-Ytterbium doped fiber)

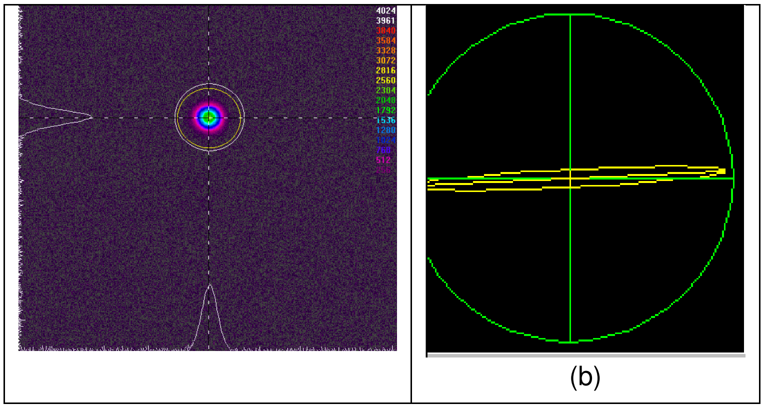

Figure 2 : laser beam profile in far field (a) and polarisation ellipsoid (b).

Using a 8W pump power source, 15 kHz of PRF has been reached, allowing hundreds of lidar signals to be averaged on each line of sight and thus speckle noise to be reduced.

Optical architecture

The optical architecture (Figure 3) is based on collimated beams, and so can be used with different fiber lasers, even with multimode fibers, since the laser output is collimated in free space. A compact circulator, based on Brewster and quarter wave plates has been specially designed, with both robustness and very good optical isolation (60 dB). A refractive afocal telescope gives to the output beam an effective Gaussian diameter of 50mm (at 1/e², with M2=1.4), allowing a focus range up to 300m.

The received beam is reflected by the Brewster plate and focused on a single mode PM fiber before being mixed with the fibered Local Oscillator.

The oscillator beam is frequency shifted by 70MHz before being amplified by the EDFA, allowing the sign of the Doppler shift to be measured.

The Figure 3 illustrates the lidar setup.

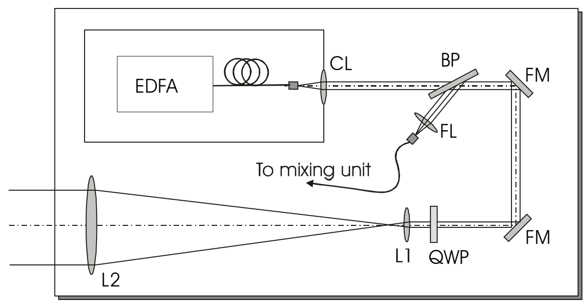

Figure 3 : Lidar setup

EDFA : Fiber Doped Power Amplifier CL : collimating lens, BP : Brewster plate, FM: folding mirror, QWP: Quarter Wave Plate, L1-L2 : afocal telescope, FL: Focusing lens

LIDAR PERFORMANCES

Taking into account the geometric and energetic lidar parameters, as well as atmospheric parameters, CNR and velocity resolution profiles can be derived from propagation models.

The figure above compares the theoretical CNR profile and the actual profile. The backscattering coefficient is assumed to be β_π=3.5 10^{-7} m^{-1} sr^{-1}.

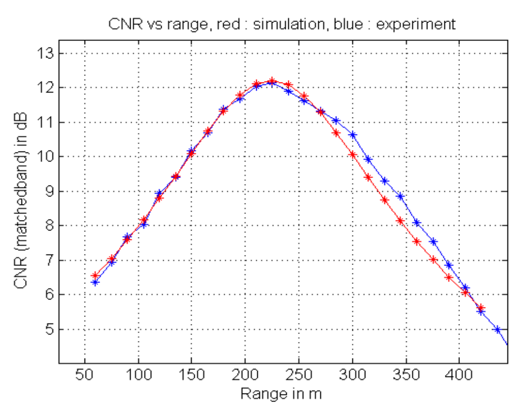

Figure 4: Theoretical and experimental CNR profile

These end-to-end models, developed at Onera were formerly used for the lidar and laser design.

SIGNAL PROCESSING

Signal acquisition

The signal is sampled and processed in real time by a DSP board. The signal is analysed by 64 points FFT, giving a basic range resolution of 37.5 meters, and a velocity resolution of 3 m/s . 60 samples overlap between successive FFTs gives a measurement spectrum every 2.4 m. With a 15 kHz PRF,100 spectra averaging and 15°/s scan speed , an angular resolution as good as 0.1 ° is obtained (35 cm at 200m). The averaged spectra are then stored for high level processing.

Man Machine Interface

In order to display the wake vortices measurements in real time, three maps are computed, having range and angle as main axes. These maps are calculated with the three first moments of the spectra, delivering respectively the CNR, the velocity centroid, and the velocity dispersion maps.

The CNR map is useful for the lidar alignment setting and focus adjustment. The velocity map gives the position and trajectory of the vortex cores. The dispersion map informs on wind turbulence.

Figure 5 shows a capture of the real time display showing a wake vortex pair 325 m away from the Lidar . Y axis is the range in m from the Lidar, X axis is the index of line of sight, linearly dependant of the scan angle. The scanner executes symmetric saw tooth trajectories so that right part of the display appears symmetric from left hand side. The color scale gives the velocity information (spectrum centroid value) on each point of the scan plane. The real time display does not inform about the maximum velocity component in the spectra, related to the wake vortex circulation. However, the presence and position of a wake vortex is clearly visible on the velocity map: wake vortex has a characteristic signature which allows the operator to stop the record when the vortex has disappeared.

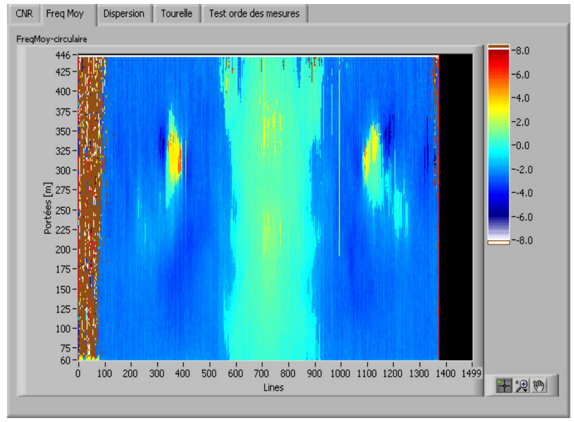

Figure 5 : Real time display of velocity map.

Post processing and wake vortex monitoring

Two signal processing methods for wake vortex analysis have been previously developed for 2 µm pulsed lidars. One is based on parametric estimation[4,5], and the other one is a direct method[6]. The outputs are vortex positions and vortex circulation as a function of time.

We have chosen to explore both methods. Comparative results with those algorithms will be presented. Figure 6 shows maximum and minimum velocity envelopes of DLR method for a scan for a wake vortex measurement in low altitude and high signal to noise ratio conditions. Each line represents a different range. X axis is the time. Y axis represents scan angle and velocity in arbitrary units. In this case, maxima measured velocity are ± 15 m/s. Positions of both wake vortices are obtained considering the coordinates (range and angle) of max velocity and min velocity for each vortex .

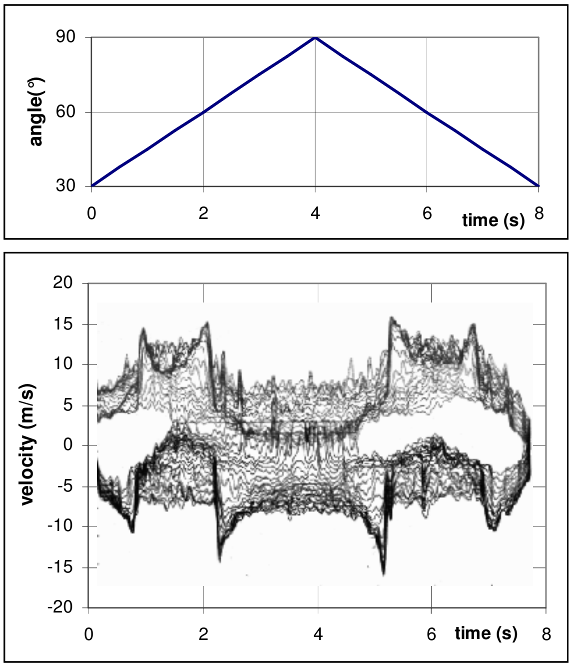

Figure 6 : Scan pattern and velocity profiles at different ranges.

CONCLUSIONS

This paper illustrates the good results obtained with a pulsed lidar based on MOPFA 1.5µm laser, for detection and monitoring of wake vortices on airport fields. Operational ranges larger than 400m have been demonstrated, with a 60µJ, 15kHz, 250ns pulse fiber doped Er laser. Wake profiles, positions and circulations can be derived from recorded data. During the next months, the system will be automated and miniaturized by Leosphere for a future deployment on airports.

Increasing the power of fiber lasers remains a topic of interest at Onera/Dota, and longer range wind lidars (800m) are expected soon.

REFERENCES

[1] G. Canat, Y. Jaouën, J.-C. Mollier, " Performances and limitations of high brightness Er^{+3}-Yb^{3+} fiber sources **",** C.R Physique 7, *Annales de l'Académie des Sciences*, Elsevier (2006)

[2] G. Canat, L. Lombard, S. Jetschke, et al., "Er-Yb-Doped LMA Fiber Structures for High Energy Amplification of Narrowlinewidth Pulses at 1.5 µm", talk CtuBB, Conf. on Lasers and Electro-Optics (CLEO), Baltimore, (2007)

[3] J.-P. Cariou, B. Augere, M. Valla, " Laser source requirements for coherent lidars based on fiber technology", C.R Physique 7, *Annales de l'Académie des Sciences*, Elsevier (2006)

[4] S. M. Hannon, J. Alex Thomson, "Real Time Wake Vortex Detection, Tracking and Strength Estimation with Pulsed Coherent Lidar", Proceedings of the 9th Conference on Coherent Laser Radar, June 23-27, 1997, Linköping, Sweden.

[5] R. Frehlich, R. Sharman, Maximum Likelihood Estimates of vortex parameters from simulated Coherent Doppler Lidar data, Journal of atmospheric and Oceanic technology, Vol 22, Feb 2005.

[6] Köpp, F., Rahm, S., and Smalikho, I. N., "Characterization of aircraft wake vortices by 2-µm pulsed Doppler lidar," Journal of Atmospheric and Oceanic Technology, Vol. 21, 2004, pp. 194-206.