DEVELOPMENT OF A FREQUENCY COMB BASED FIBER LIDAR FOR CO_2 MEASUREMENTS

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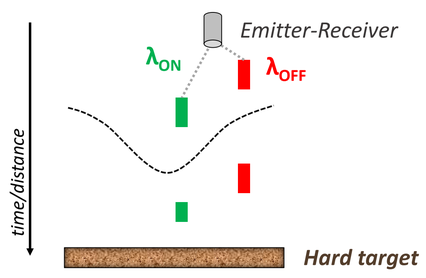
CONTEXT

INTEGRATED PATH DIFFERENTIAL ABSORPTION LIDARS (IPDA)

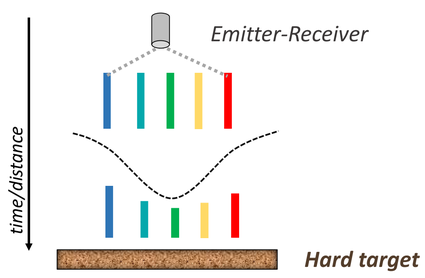
Lidar technology (Differential Absorption - DIAL) has proven to be a powerful tool for remote sensing of atmospheric trace gases (e.g. CO_2, CH_4 or H_2O).

TRADITIONAL DIAL:



- Sequential emission: time lag between the emitted wavelengths
- Need of complex frequency stabilization systems (~1MHz)
+ Direct detection possible

FREQUENCY COMB LIDAR:



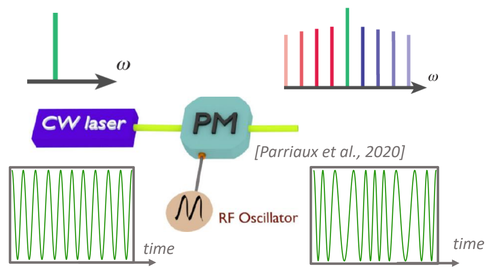
+ Simultaneous emission (no time lag)
+ More robust to laser frequency drifts or frequency shifts of the absorption line
- Coherent detection required: speckle

Objective: Electro-Optic Frequency Comb Lidar for CO_2 IPDA measurements @1572 nm

ELECTRO-OPTIC FREQUENCY COMBS

GENERATION:
ELECTRO-OPTIC MODULATION

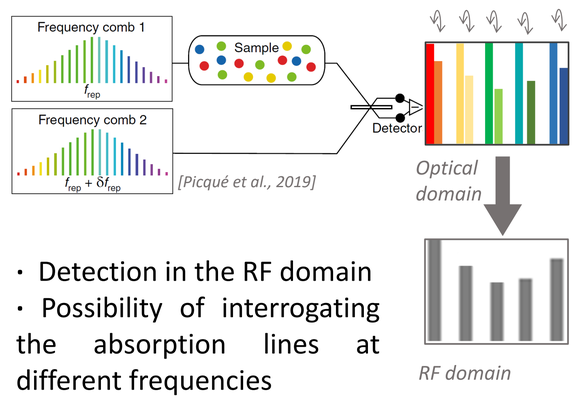
It is possible to generate a multi-frequency optical signal by modulation of a CW laser.



- The optical power can be concentrated in a small number of comb lines (10 - 10^3)
- Highly tunable
- All-fiber setup

DETECTION:
DUAL COMB SPECTROSCOPY

To identify all the frequency components, we detect the interference of the probe comb with a second comb (local oscillator comb).



- Detection in the RF domain
- Possibility of interrogating the absorption lines at different frequencies

LIDAR DEVELOPMENT

EXPERIMENTAL DESIGN

A lab prototype of the IPDA comb lidar was developed. We conducted gas spectroscopy of CO_2 and C_2H_2 (acetylène) in a lidar configuration. The lab prototype was used to validate the performance model, optimize experimental parameters and to identify instrumental sources of error in the gas concentration measurement.

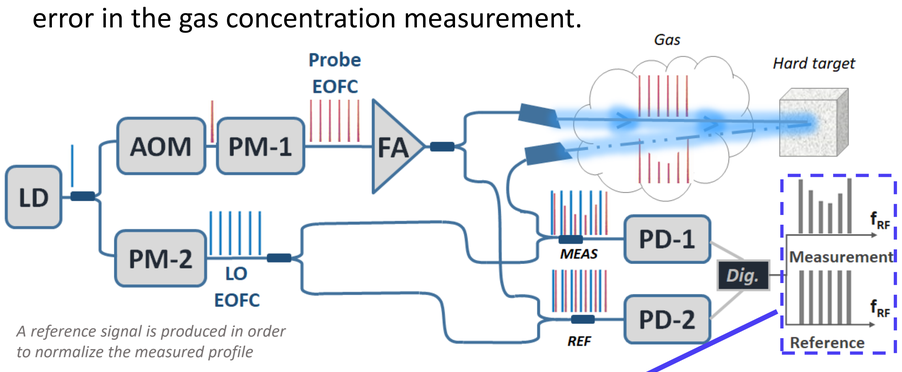
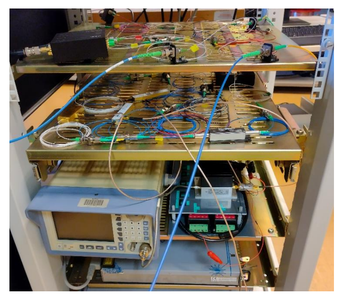
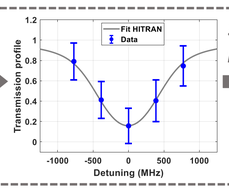


Photo of the all- fiber setup



LD: *laser diode*
AOM: *acousto-optic modulator*
PM: *phase modulator*
FA: *fiber amplifier*
PD: *photodetector*

1. Compute experimental transmission profile → $T_{exp}(\omega_n)$ *2. Fit to theoretical profile* →  *3. Infer concentration (multi-parameter inversion)* → p_c : *VMR x gas column length*; ⇨ λ : *Central wavelength*

Principle of measurement

PERFORMANCE MODEL

Speckle arises when a laser beam interacts with a rough surface. Speckle fluctuations are an important source of noise in coherent lidars.

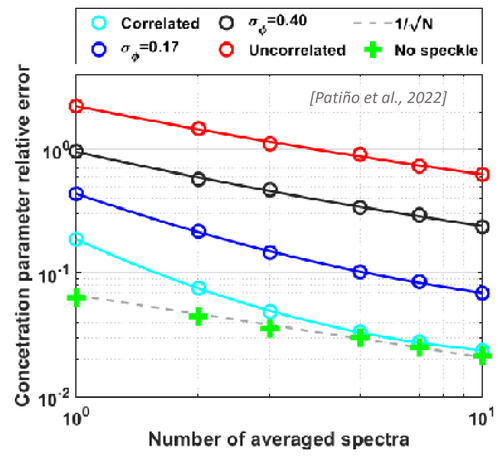
In a dual comb lidar, speckle fluctuations of the different frequency components may be correlated depending on the roughness of the backscattering surface.

$$\sigma_\phi = \frac{4\pi f_M \sigma_z}{c}$$

Modulation frequency

Surface mean roughness

- $\sigma_\phi \approx 0$: correlated speckle noise
- $\sigma_\phi > 1$: uncorrelated speckle noise

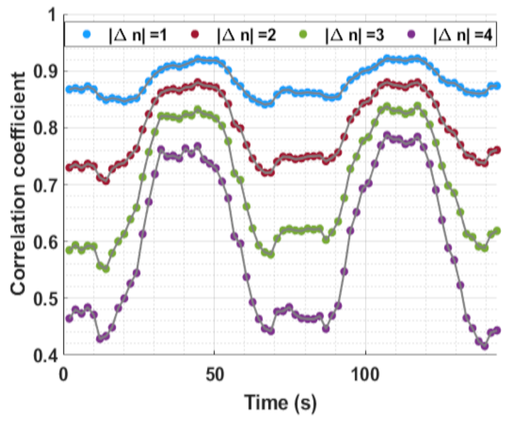


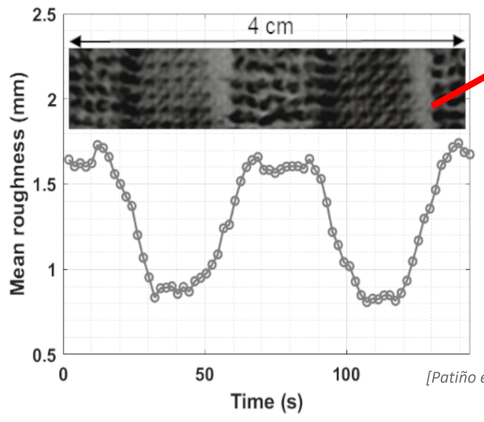
Hence, the error in the gas concentration measurement depends on the roughness of the backscattering surface. Speckle correlation has a beneficial effect on the IPDA measurement precision.

EXPERIMENT RESULTS

SURFACE CHARACTERIZATION

Since speckle correlation depends on the surface properties, we can use a dual comb-based lidar to remotely characterize a backscattering surface.



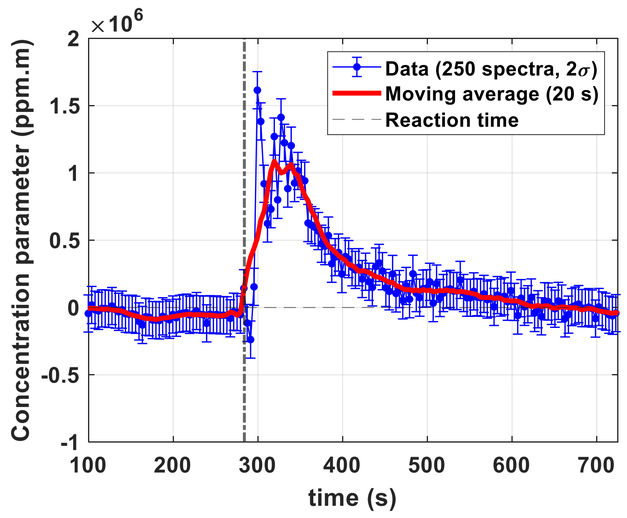


Textile sample

[Patiño et al., 2022]

By measuring the correlation coefficient of the speckle fluctuations it is possible to infer the surface roughness profile.

CO_2 CONCENTRATION MEASUREMENT IN FREE SPACE



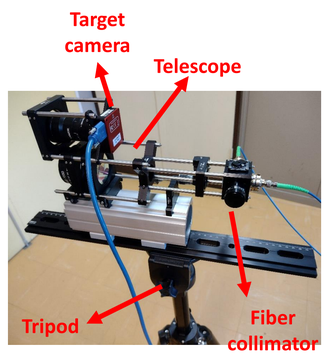
We used the bi-static system to measure the **CO_2** concentration produced in a reaction of **vinegar + baking soda** in a PVC tube.

Unlike traditional DIAL lidars, no frequency reference was needed. The central wavelength of the frequency comb can be estimated by means of a multi-parameter inversion.

CONCLUSIONS & PERSPECTIVES

The performance of a dual comb IPDA lidar has been assessed theoretically and experimentally. We have also demonstrated the use of speckle noise correlation for remote surface characterization.

Current works are focused on the development of a mono-static, pulsed lidar for long-range measurements of atmospheric CO_2.



PUBLICATIONS & REFERENCES

[1] **W. Patiño and N. Cézard**, "Electro-optic frequency comb based IPDA lidar: assessment of speckle issues," Opt. Express 30, 15963-15977 (2022).
[2] **W. Patiño and N. Cézard**, "Coherent Electro-Optic Frequency Comb Lidar for CO2 IPDA measurements: preliminary design and speckle issues", 21st Coherent Laser Radar Conference.
[3] A. Parriaux, K. Hammani, and G. Millot, "Electro-optic frequency combs," Adv. Opt. Photonics 12(1), 223–287(2020).
[4] Nathalie Picque and Theodor W. Hänsch. Frequency comb spectroscopy, Review Article. Nature Photonics 13, 146-157 (March 2019).
[5] Philippe J. Hebert, Francois Lemaître. SCALE: validations and prospects for a novel type of sounding lidar using short frequency combs. ICSO 2018 International Conference on Space Optics Chania.
[6] **N. Cézard**, A. Dolfi-Bouteyre, A. Durécu, B. Faure, D. Goular, F. Gustave, P-J. Hébert, J. Lahyani, J. Le Gouët, F. Lemaître, L. Lombard, **W. Patiño**, C. Planchat, M. Valla, "Recent advances on fiber-based laser and lidar systems for future space-borne monitoring of greenhouse gas", in Proc. Of International Conference on Space Optics (2021).