Optical Filtering for Onboard LIDAR Calibration

Introduction: The understanding of the global carbon cycle for a prediction of the rate of **climate change** during the 21st century is considered one of the greatest scientific challenges. There is an urgent need to provide accurate measurements of CO_2 on a global scale to quantify carbon fluxes and their interactions with the climate system. Atmospheric CO_2 is the most important anthropogenic greenhouse gas and contributes to ~2/3 to the overall global radiative forcing by long-lived greenhouse gases. Due to human activities, the concentration of **carbon dioxide** (CO_2) has alarmingly grown by about 42% since pre-industrial ages.

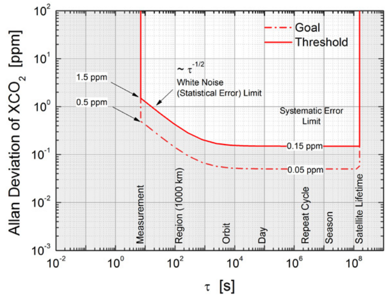
The **Integrated Path Differential Absorption Lidar** (IPDA) technique using hard target reflection in the near IR has the potential to deliver CO_2 column measurements from space with unprecedented accuracy. IPDA largely eliminates the contribution of atmospheric scattering by particles and clouds which greatly affects the achievable accuracy of passive remote sensing instruments. Moreover, this technique can be applied during daytime or night-time and at all latitudes since it does not depend on solar radiation.

Comprising an IPDA instrument **A-SCOPE** (Advanced Space Carbon and Climate Observation of Planet Earth) was investigated by ESA as a prephase-A Earth Explorer Mission. A-SCOPE was not selected as an Earth Explorers core mission due to lacking technology readiness; therefore, technology studies such as the one at hand are continued. In the US, NASA is pursuing a similar concept with ASCENDS (Active Sensing of CO2 Emissions over Nights, Days, and Seasons). The IPDA technique will also be employed by the German-French climate mission MERLIN (Methane Remote Sensing LIDAR Mission) for methane as the target greenhouse gas.

Motivation: The necessity to achieve high relative accuracy demands for very stringent system specifications. Two of the most prominent potential sources of systematic error of the IPDA technique are the the frequency stability of the laser source in the Near IR spectral range and the energy calibration of the outgioing laser pulses. Within the frame of this project these two issues were investigated in detail: at Laboratoire Temps-Fréquence (LTF) of **Université de Neuchâtel,** Switzerland, a compact frequency reference breadboard was designed to meet the specifications for on-line laser frequency stabilization. The second requirement, looked after by the Institute of Atmospheric Physics of **DLR,** Germany, relates to the monitoring of on-line to off-line ratio of outgoing pulse energies. The outcome of the project is not only applicable to CO_2, but also to other atmospheric constituents (CH_4, H_2O,…)

Requirements' Definition

The concepts of "systematic error" and "random error" may be interpreted in terms of uncorrelated and correlated measurement noise, respectively. It is, however, important on

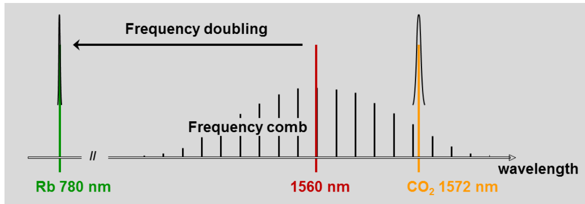


which timescales these specifications have to be met. Therefore, a methodology was implemented for an IPDA lidar system that gives rise to the individual timescales involved and serves as a benchmark to assess the observing of requirements defined for this project. It uses the well-known Allan deviation which is a powerful tool to identify and quantify these different types of noise sources. The Figure above gives an example of how the requirements are transferred into a template for goal and threshold requirements.

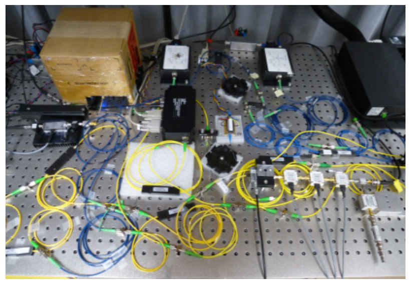
Frequency Reference

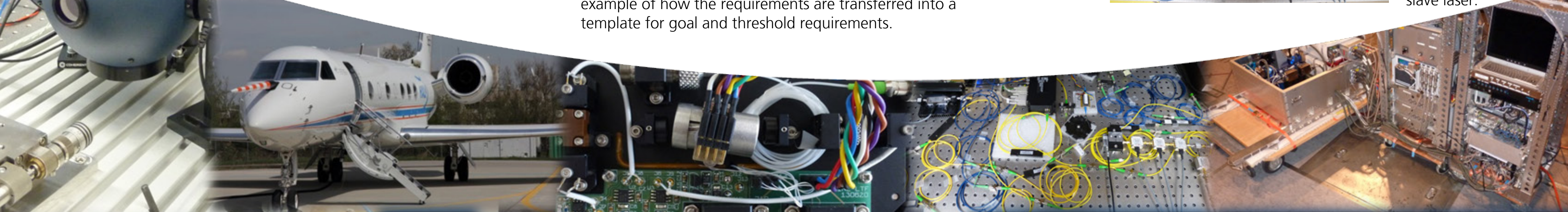
To meet the stringent requirements on laser frequency stability, a concept was devised that uses a frequency comb which is locked to an ultrastable Rubidium (Rb) line.

Concept: The unique frequency stabilisation concept devised by LTF uses a DFB diode laser at 1560nm. This laser is stabilized onto Rb using frequency doubling. In order to bridge the wavelength gap between 1560nm and the CO_2 absorption line at ~1572nm an **optical frequency comb** is used that is driven by an electro-optic modulator. Finally, the (slave) laser that needs to be matched to the CO_2 line is locked to an adequate comb tooth.



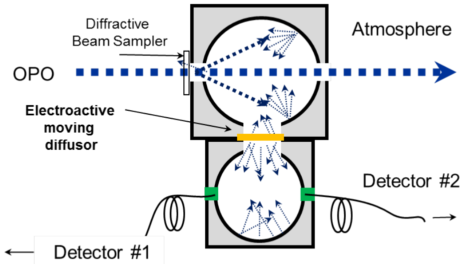
Breadboard: The concept was successfully translated into a frequency monitoring breadboard (FMB) (see figure below). It could be proven that it even exceeds the expectations on frequency stability. The FMB can be used as frequency reference either in a heterodyne setup or as a frequency stabilized seeding source for the lidar transmitter. Its wave-length is not restricted to 1572nm but can be easily adapted to any wavelength in the range 1545nm to >1575nm, by changing the slave laser.





Energy Monitoring

Challenge: For the monitoring of the on-line to off-line ratio of outgoing pulse energies of the lidar transmitter the preferred set-up would use identical detectors for both lidar signal and pulse energy monitor to circumvent potential detector ageing effects. It is thus important to employ pick-up, attenuation, transmit and detection schemes that do not alter the energy ratio. For this purpose, a test-bed employing a narrow-band optical parametric oscillator (OPO) that is capable to emit the required on- and off-line pulses within a double pulse sequence of ~ 300µs was used. For the energy monitoring, the use of **integrating spheres** appear to be attractive since those are insensitive to beam pointing and intensity profile variations and can be fibre-coupled. However, In detailed investigations it could be shown that the speckle patterns at the exit port of integrating spheres of two subsequent pulses within a double-pulse sequence appear to be partly correlated. It is thus required to destroy this correlation to meet the requirements.



Proof of Concept: Following an extended series of experimental studies, a concept was chosen using a double-sphere set-up in which an electro-active moving diffusor decorrelates the speckle pattern (see figure above). This scheme could fortunately been **tested on board of an aircraft** as part of the receiver of a combined CO_2 and CH_4 lidar system that has been developed at DLR. Since this concept proved to be very successful in various research flights it provides important guidance for a spaceborne deployment.

Flyer, „optical Filtering for Online Lidar Calibration"

Project Partners

Prime Contractor:

Deutsches Zentrum für Luft-
und Raumfahrt (DLR) e.V.,
Institut für Physik der Atmosphäre,
82234 Oberpfaffenhofen, Germany
http://www.dlr.de/ipa

Subcontractors:

Université de Neuchâtel,
Laboratoire Temps-Fréquence,
Avenue de Bellevaux 51,
2000 Neuchâtel, Switzerland
www2.unine.ch/ltf

OHB System AG
Wolfratshauser Str. 48
81379 München, Germany
www.ohb-system.de

ESA Technical Officers:
- João Pereira do Carmo
- Eamonn Murphy

Further Information :

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- R. Matthey, F. Gruet, S. Schilt, and G. Mileti, *Compact rubidium-stabilized multi-frequency reference source in the 1.55-µm region*, Opt. Lett. 40 (11), 2576 (2015).

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