Multichannel FMCW lidar for imaging velocimetry and range finding

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Applied Infrared Spectroscopy Lab

EGU General Assembly
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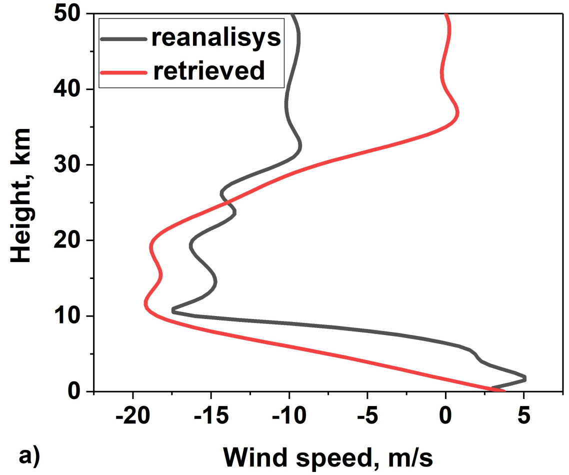
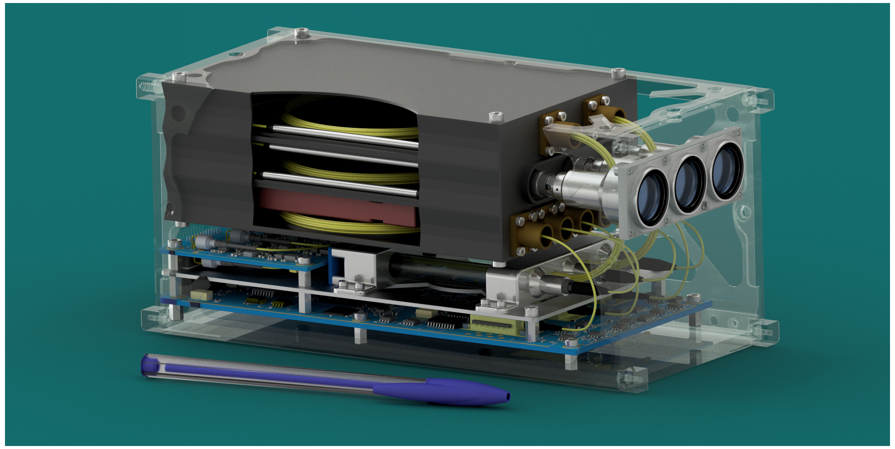
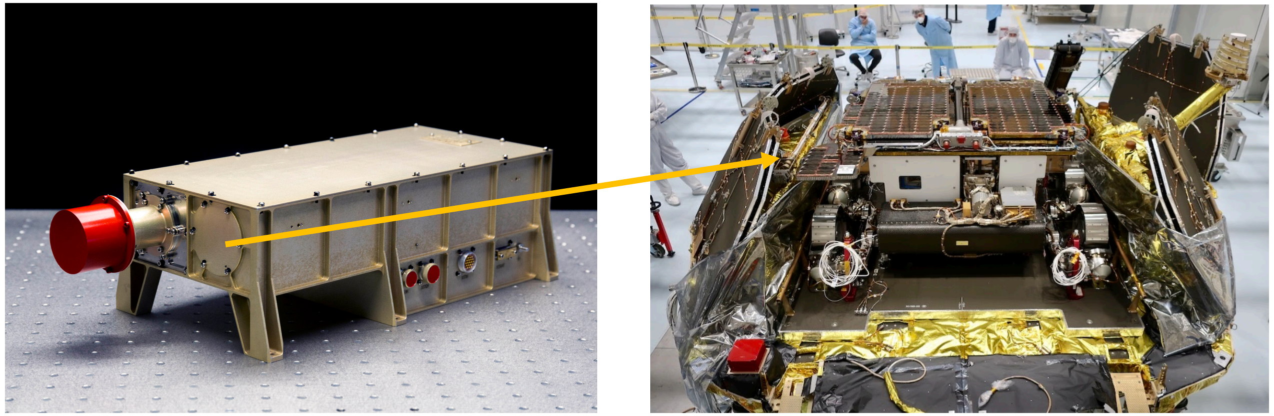
Introduction to AIRS Lab



We are developing MLHS instrument for greenhouse gases remote sensing from troposphere to lower mesosphere. Thereby, restore GHG concentration and windspeed profiles. doi.org/10.5194/amt-13-2299-2020



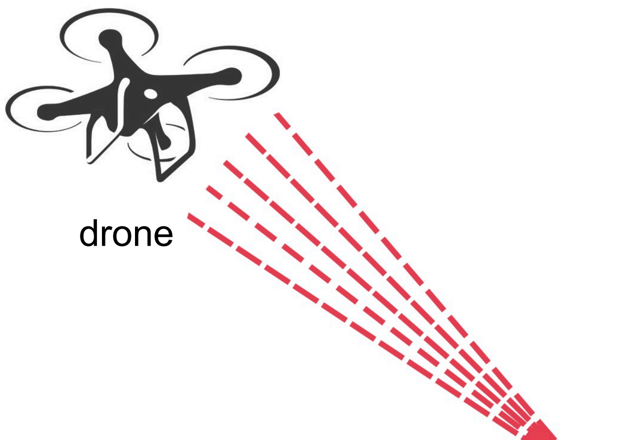
Currently we are working on IVOLGA instrument which is a heritor of MLHS with the purpose of remote sensing of CO2 concentration and wind speed measurements in Venusian mesosphere in Shukrayaan-1 mission framework



M-DLS instrument was constructed for local measurements of H_2O, HDO and CO_2 concentration variation during one Martian year onboard ExoMars-2022 lander. doi.org/10.3390/app10248805

We are also utilizing UAVs for arctic ice exploration with Synthetic Aperture Radar

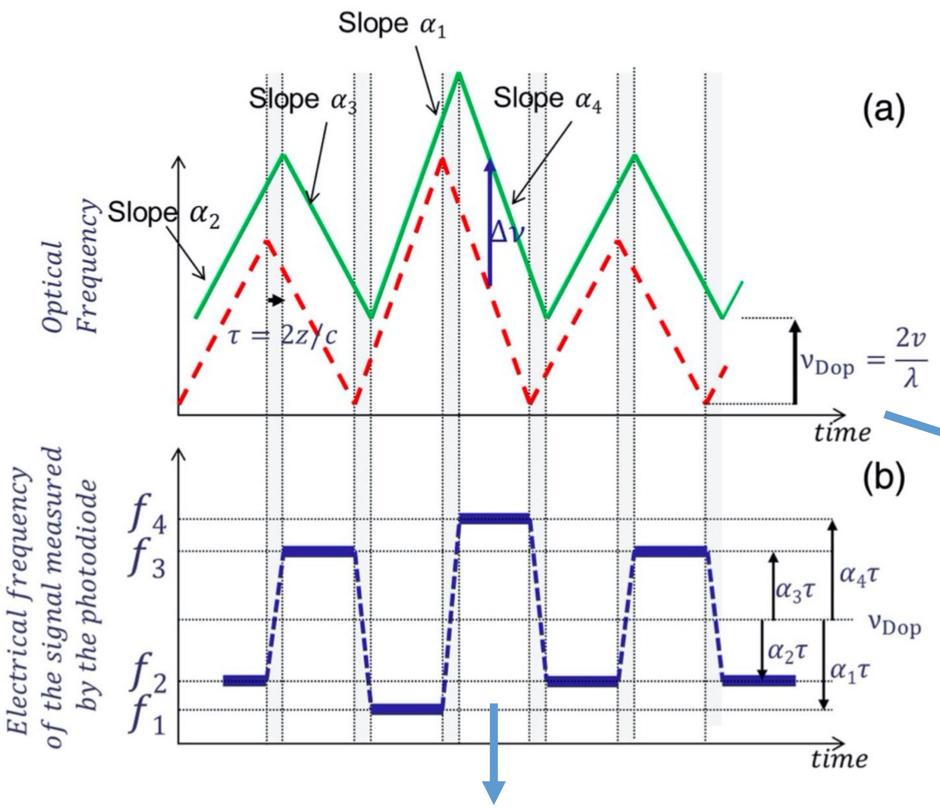
How Lidars function



FMCW lidar

Specs of proposed lidar:
Distance: up to 50m
Number of pixels: 8

Drone detection in cities is the main application for this project. Frequency Modulated Continuous Wave (FMCW) lidar fit this task best because of simultaneous distance and speed measurement. For faster data acquisition we implement a multichannel design



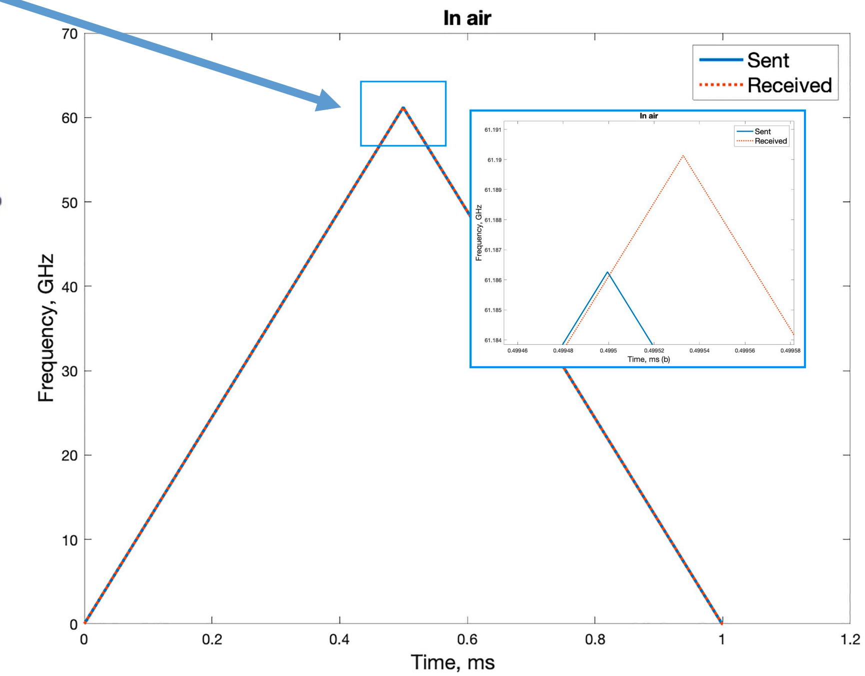
The target speed and distance are:

$$R = \frac{c}{4\gamma}\left(f_{down} - f_{up}\right) \qquad (1)$$

$$v = \frac{\lambda}{4}\left(f_{down} + f_{up}\right). \qquad (2)$$

Principle of operation of FMCW lidar [P. FENEYROU et al. Frequency-modulated multifunction lidar for anemometry, range finding, and velocimetry– 1]

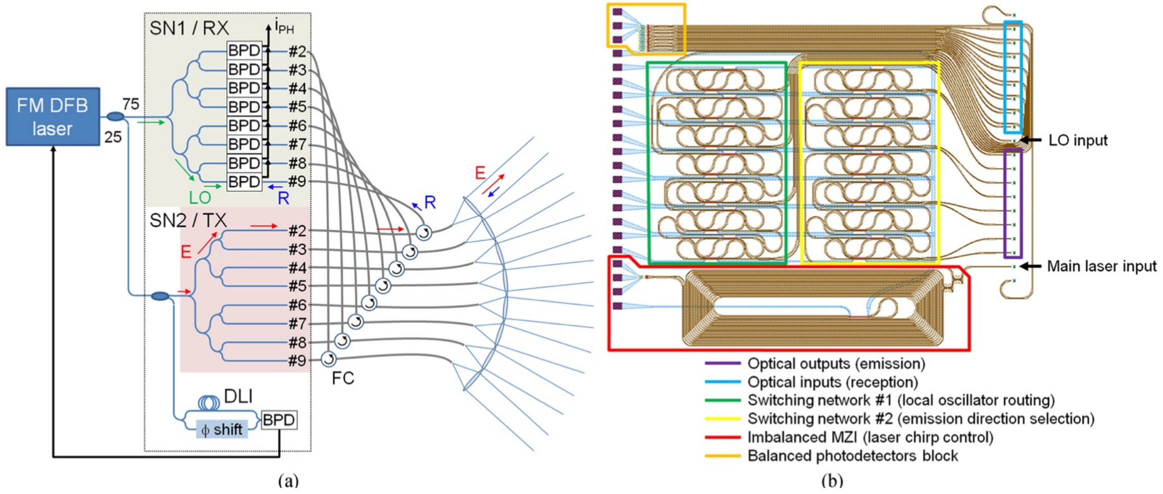
In real life conditions the difference in frequency is much smaller

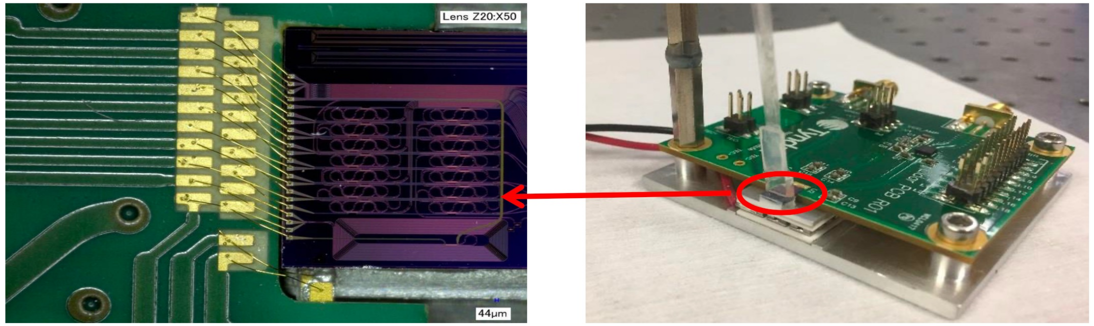


Simulation of sent and received laser signal. Distance to target is 5 m, speed is 3 m/s

Multichannel lidar overview

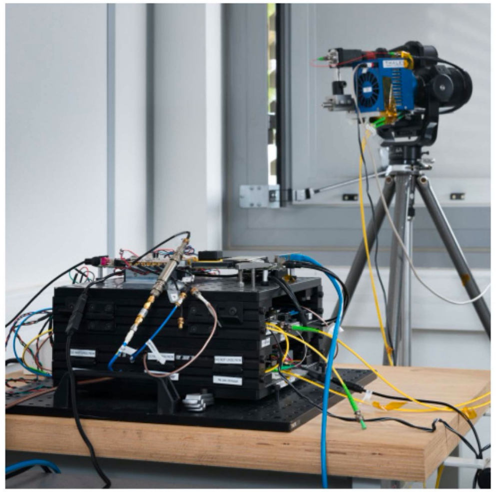
1)





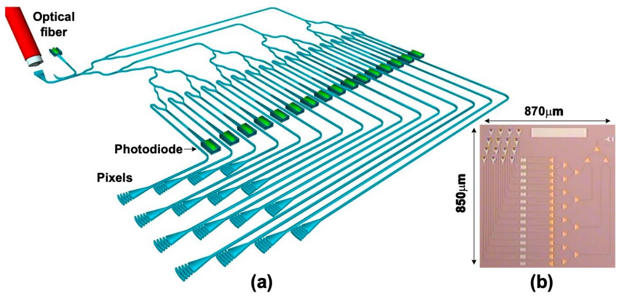
A. Martin et al. Photonic Integrated Circuit-Based FMCW Coherent LiDAR
DOI: 10.1109/JLT.2018.2840223

2)



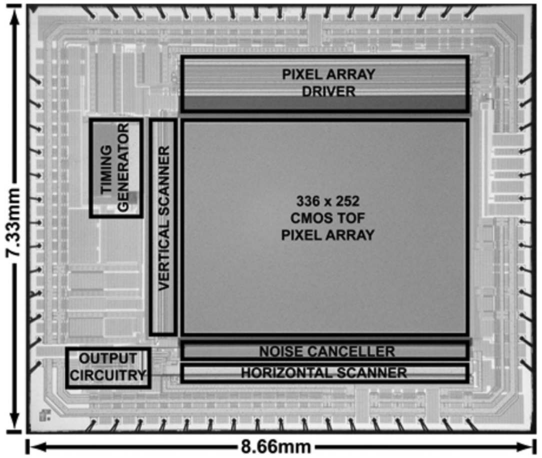
P. FENEYROU et al. Frequency-modulated multifunction lidar for anemometry, range finding, and velocimetry—2. Experimental results
DOI:10.1364/AO.56.009676

3)



Firooz Aflatouni et al. 4x4 Nanophotonic coherent imager
DOI:10.1364/OE.23.005117

4)



Shoji Kawahito et al. A CMOS Time-of-Flight Range Image Sensor With Gates-on-Field-Oxide Structure
DOI:10.1109/JSEN.2007.907561

Frequency chirp linearization

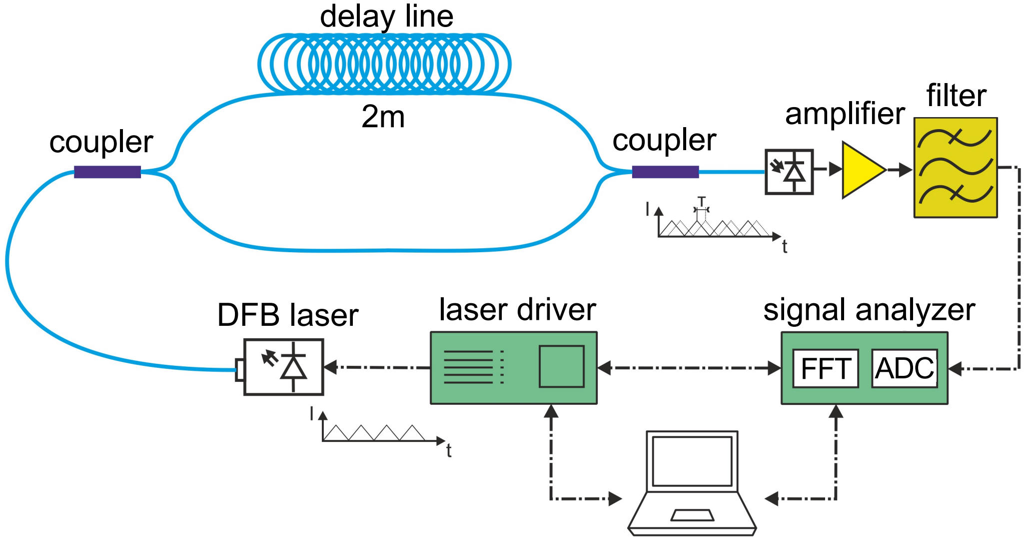
After mixing initial laser light with the light from the delay line we observe beat signal with the frequency:

$$f_{beat} = \frac{L_{delay}}{c}\frac{f_{BW}}{T_{modul}}$$

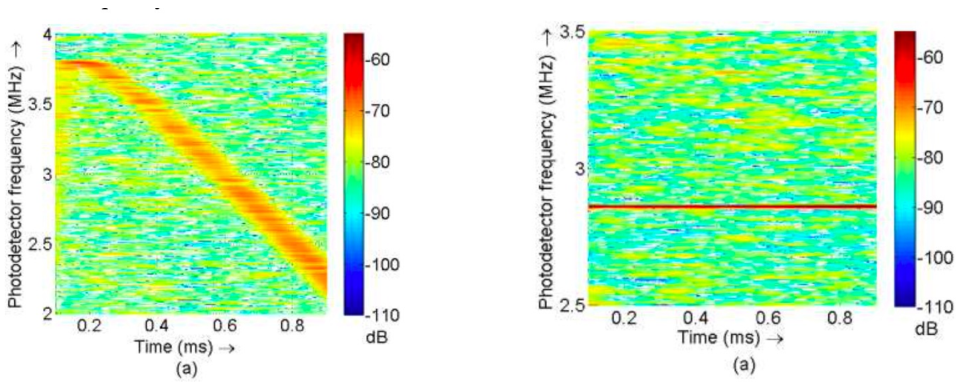
The range resolution δz of an FMCW range measurement is determined by the total frequency excursion *B* of the optical source:

$$\delta z = \frac{c}{2B}$$

where *c* is the speed of light. The key component of an FMCW imaging system is therefore a broadband and precisely controllable swept frequency source.

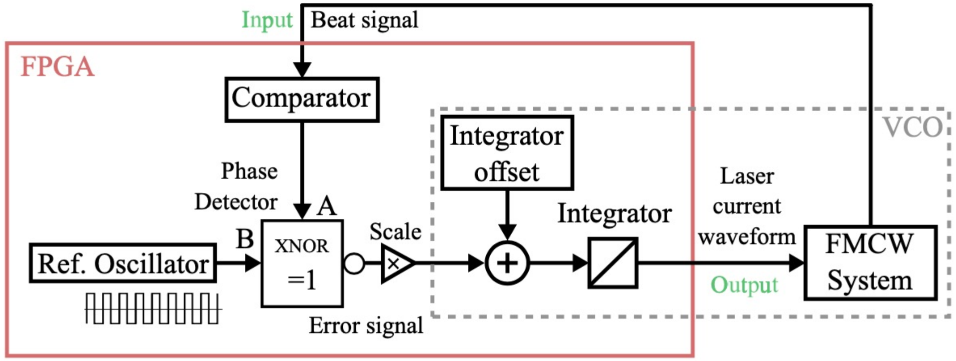


Delay line optical scheme for frequency chirp linearization



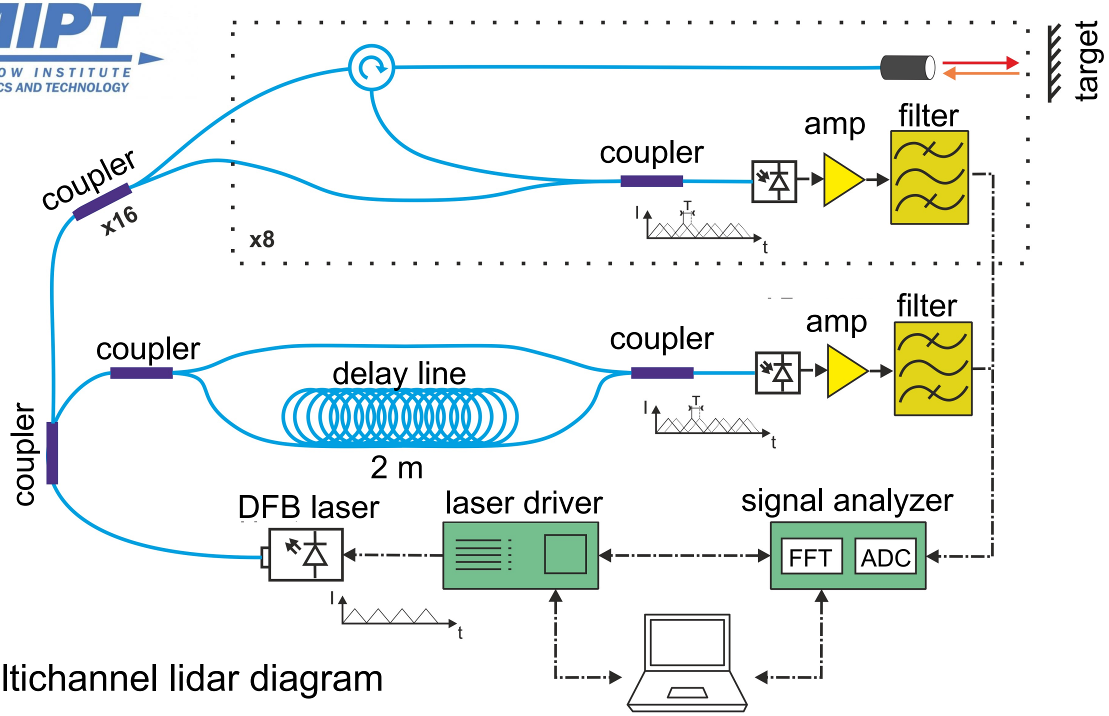
(a) Measured spectrogram of the output of the loop photodetector when the PLL is off; (b) when PLL is on. [Naresh S. et al, Precise control of broadband frequency chirps using optoelectronic feedback]

We can implement phase-locked loop on FPGA to retain beat frequency constant

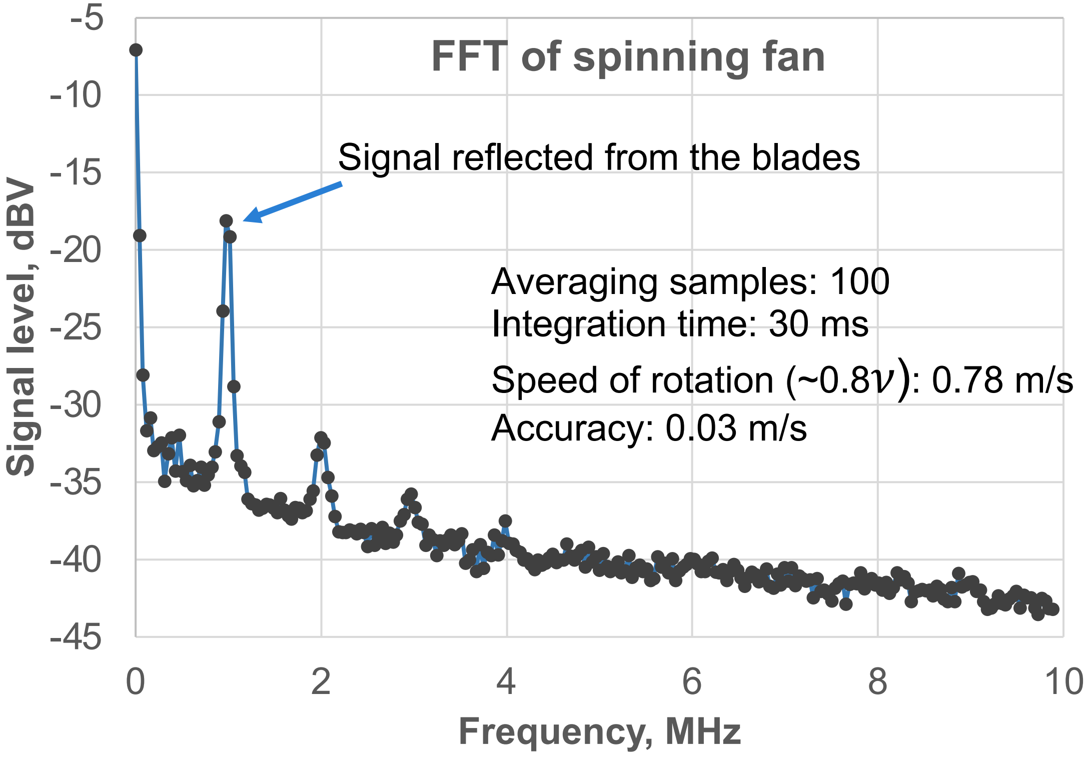


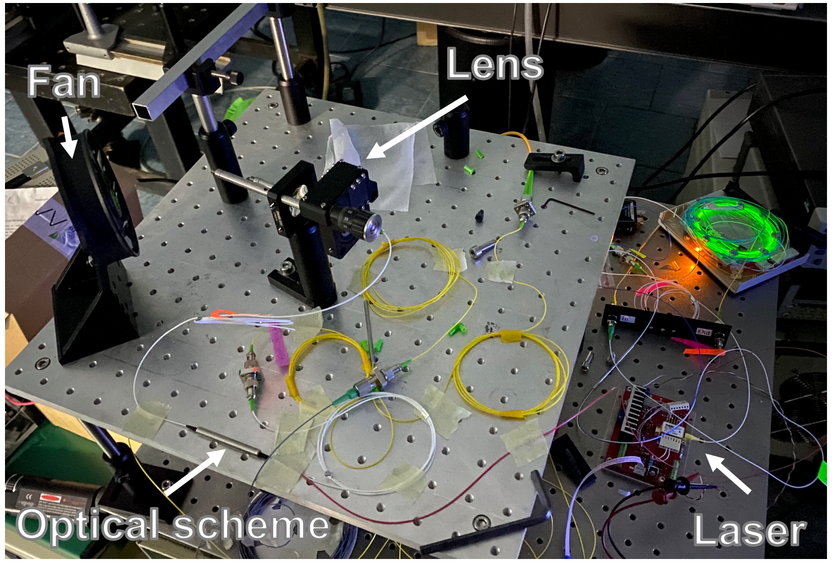
PLL algorithm schematic for FPGA. [Fabian M. M. et al, Frequency-modulated laser ranging sensor with closed-loop control]

Moving target experiment

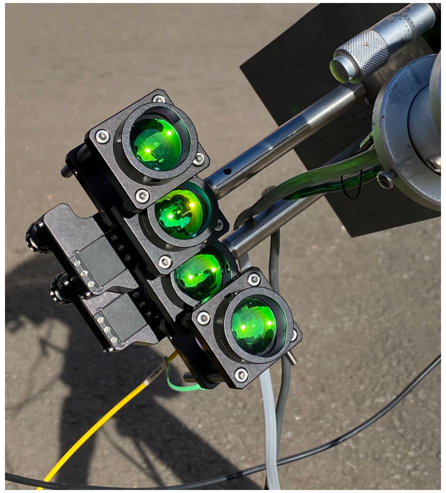


Multichannel lidar diagram





Receiving signal reflected from spinning fan



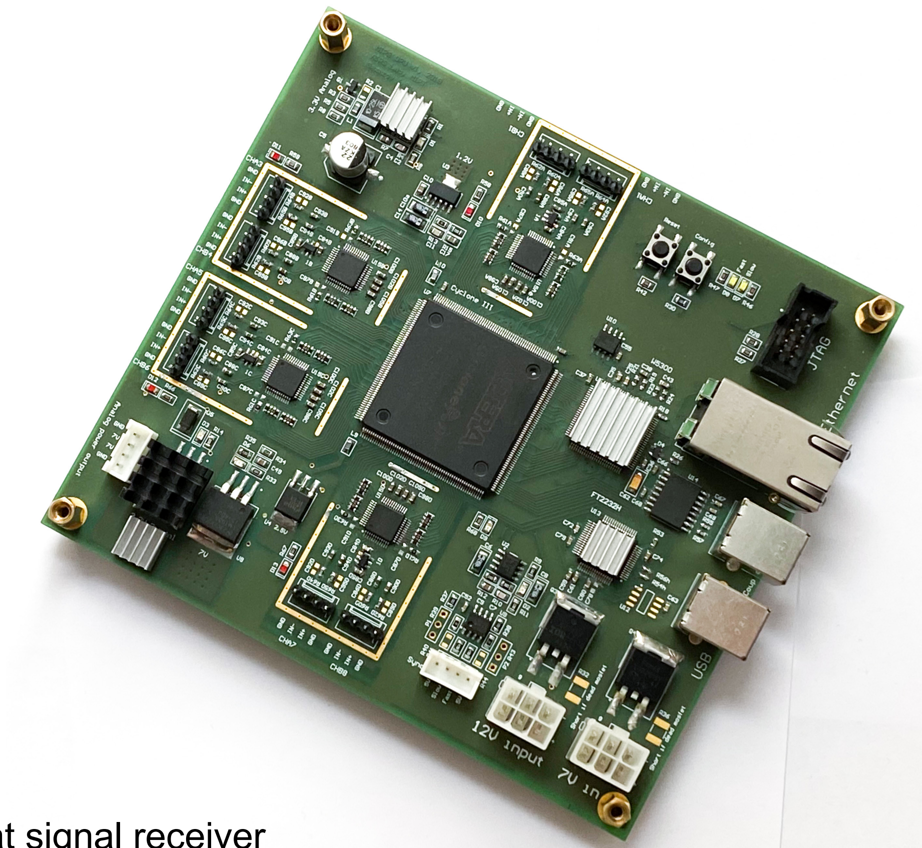
Multichannel design is inherited from already working MLHS instrument

Project status:

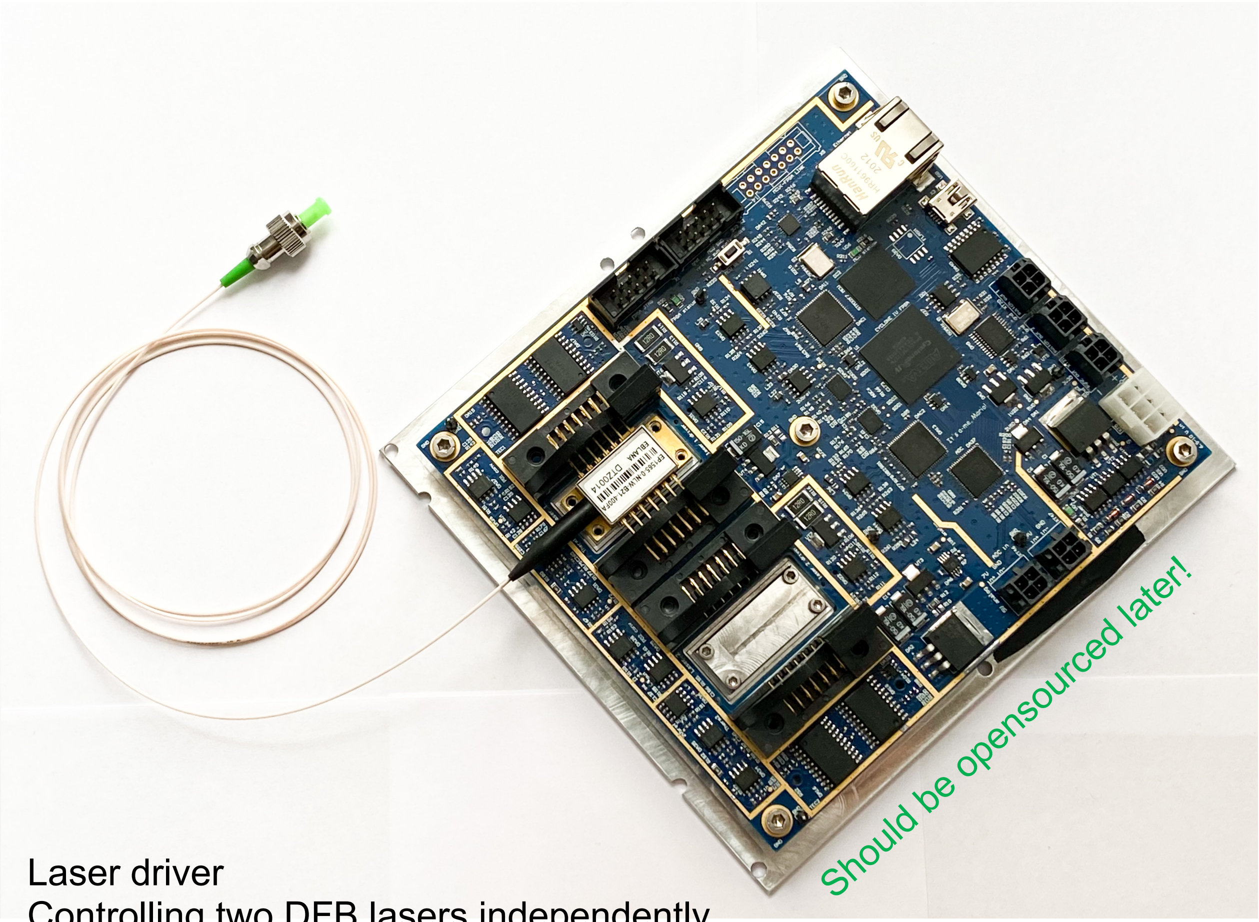
1) FFT core implementation on FPGA
2) Beat signal observation in delay line
3) Experiments on moving target
4) Custom laser driver board development
5) Chirp linearization controller implementation
6) Multichannel design testing

Custom developments in multichannel design

It’s not too hard to build an FMCW lidar, but to make it perform fast and multichannel complicate things. After first experiments it became clear that COTS products are not flexible/affordable enough for multichannel design. Thus we are developing our boards:



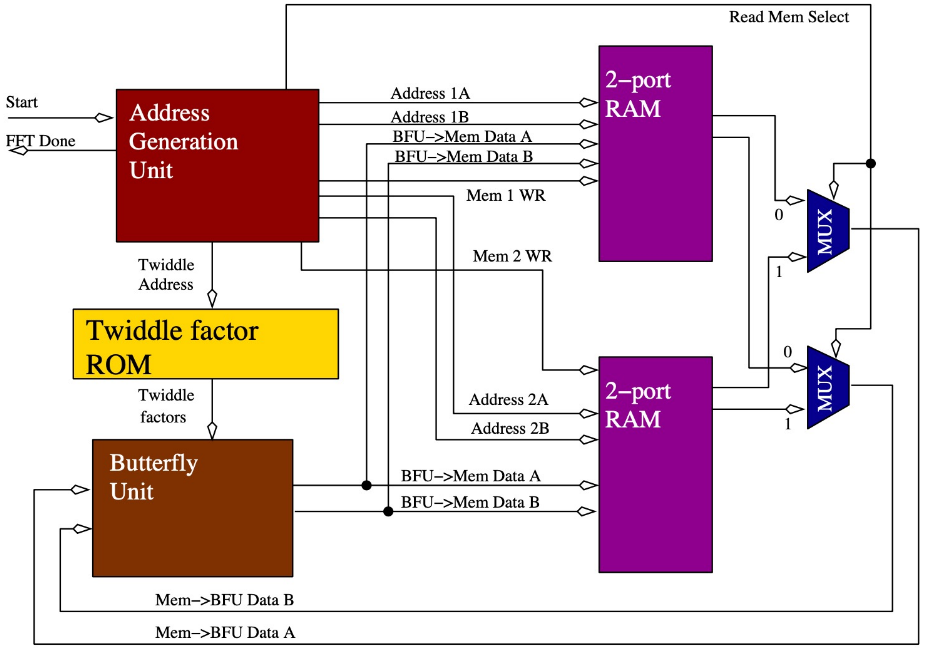
Beat signal receiver
Eight channels working simultaneously
Performing 20 MHz 2048 point FFT calculations



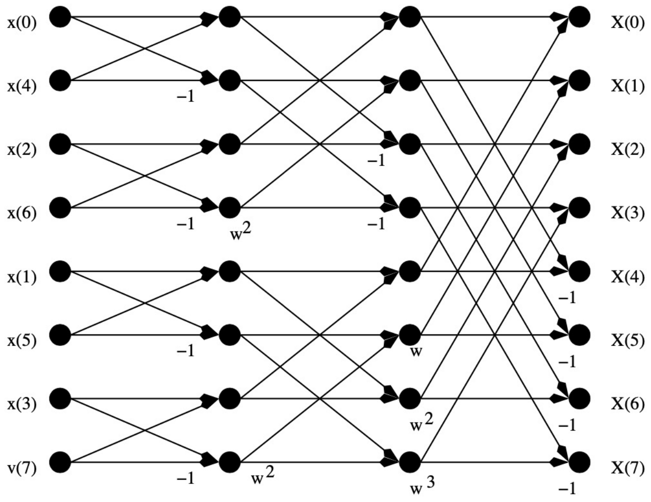
Should be opensourced later!

Laser driver
Controlling two DFB lasers independently
With chirp repetition rate faster than 100 kHz

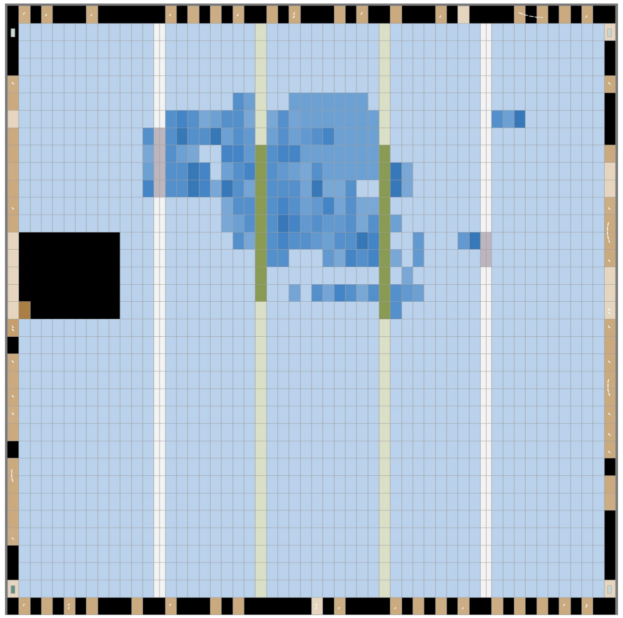
FFT on FPGA



How FFT works in FPGA [G. William Slade. The Fast Fourier Transform in Hardware: A Tutorial Based on an FPGA Implementation]



Signal flow through the FFT core

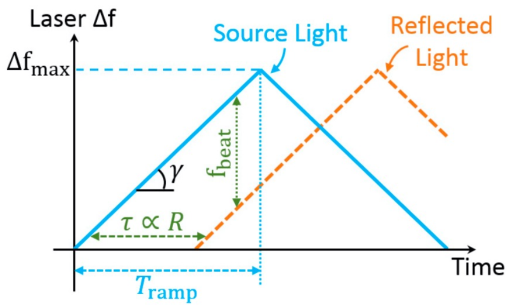


FFT core synthesized inside FPGA

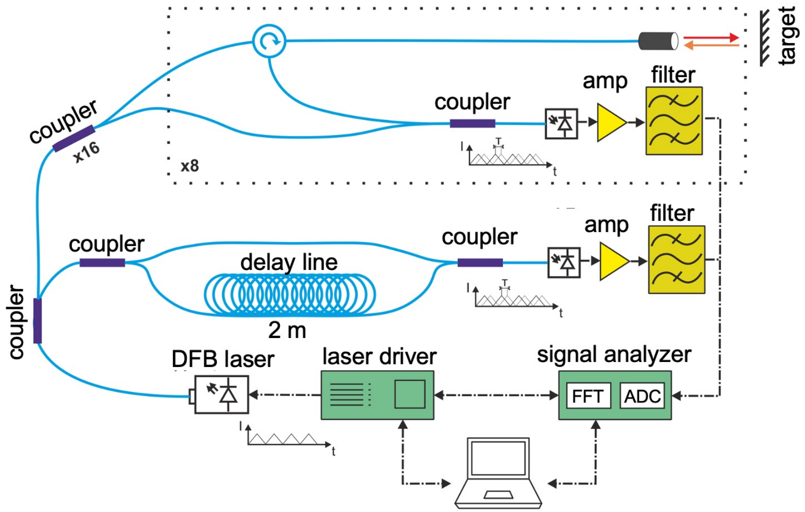
FFT core specs:

Core frequency	100 MHz
FFT Bandwidth	10 MHz
FFT points	2048
Core cycles per spectrum (delay)	12000 (0.2 ms)

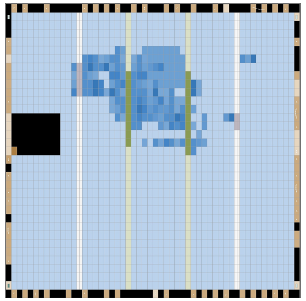
We perform two FFT per period for distance and speed problem solution. Data flow is up to 250 mbit/s if all 8 channels work in parallel with 2 transforms at 1 kHz



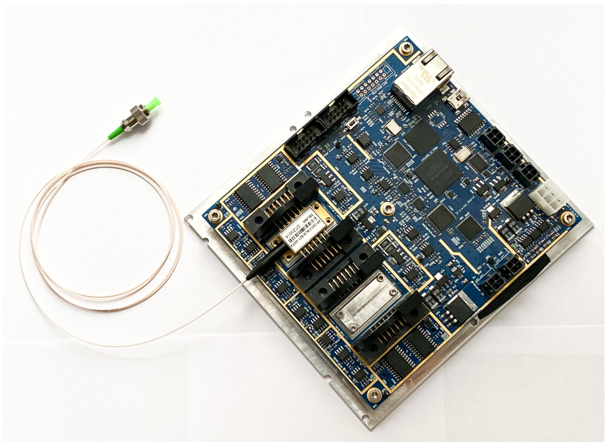
Principle of operation



Multichannel lidar diagram



FFT on FPGA



Our own design

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