JRP IND53 “Metrology for large volume measurements”
LUMINAR

Air index compensation for absolute distance measurements

Jean-Pierre Wallerand, Joffray Guillory, Daniel Truong, Christophe Alexandre

Conservatoire National des Arts et Métiers, Paris, France.

EMRP
European Metrology Research Programme
Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

le cnam

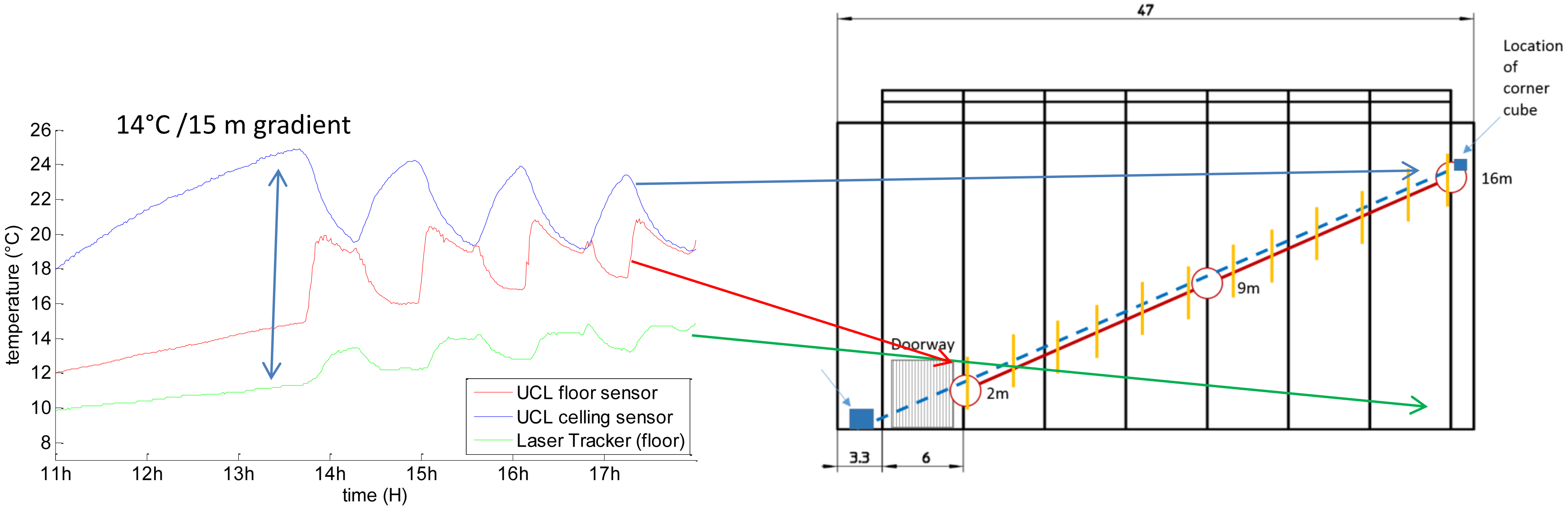
Workshop luminar, Teddigton NPL, 18th May 2016

Motivation

- Any laser based distance measurement is limited by the knowledge of the air index: 500 µm/50m/10°C.

Motivation

- Any laser based distance measurement is limited by the knowledge of the air index: 500 µm/50m/10°C.



Motivation

- Any laser based distance measurement is limited by the knowledge of the air index: 500 µm/50m/10°C.
- Is there a solution for measuring a distance without knowledge of actual air index ?
- In principle: Yes
- In practice: The objective of our work

le cnam

INTRODUCTION

- Absolute distance measured by the phase shift of an AM laser beam during its propagation in air:

$$L = \frac{1}{2} \times \frac{\phi_{(rad)}}{2\pi} \times \frac{c}{n_{air} \cdot f_{RF}}$$

Frequency of the modulation

Phase shift during propagation

Air index: model the speed of propagation in air

f_r can be known at 10^{-9} level using quartz oscillators

$\phi_{(rad)}$ can be measured with an accuracy compatible with µm uncertainty for 5 GHz of modulation frequency.

It can be demonstrated that in wet air (pw=0):

$$L = L_{0_1} - A(\lambda_1, \lambda_2)\left(L_{0_2} - L_{0_1}\right)$$

True distance

Distance measured at λ_1 for n=1

Distance measured at λ_2 for n=1

Similar formula for dry air (taking into account p_w)

L is measured without any knowledge of air temperature and atmospheric pressure

A is an amplification factor of the dispersion (and the error) on L_{02}-L_{01} measurement.
For A(1550 nm, 785 nm)= 50, a 100µm uncertainty on L requires a 2 µm uncertainty on L_{02}-L_{01} !

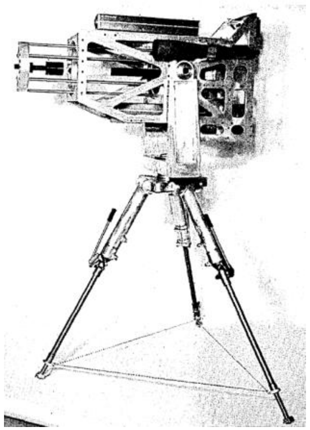
le cnam

INTRODUCTION: air index compensation
« *History* »

An instrument has already been developed and used in the past for kilometric range application:

- Earnshaw K B and Owens J C 1967 Dual wavelength optical distance measuring instrument, which corrects for air density *IEEE J. Quantum Electron.* ***3* *544–50***
- Earnshaw K B and Hernandez E N 1972 Two-laser optical distance-measuring instrument that corrects for the atmospheric index of refraction *Appl. Opt.* **11 749–54**

Terrameter



1972 → 1983

Jean Gervaise, Michel Mayoud, Test of global positioning system on the CERN-LEP control network, European Organization for nuclear research, 1985

2008: PTB, air index compensation using interferometry

- Meiners-Hagen & Abou-Zeid, MST 19, 084004 (2008)

PTB: later in the workshop using interferometry

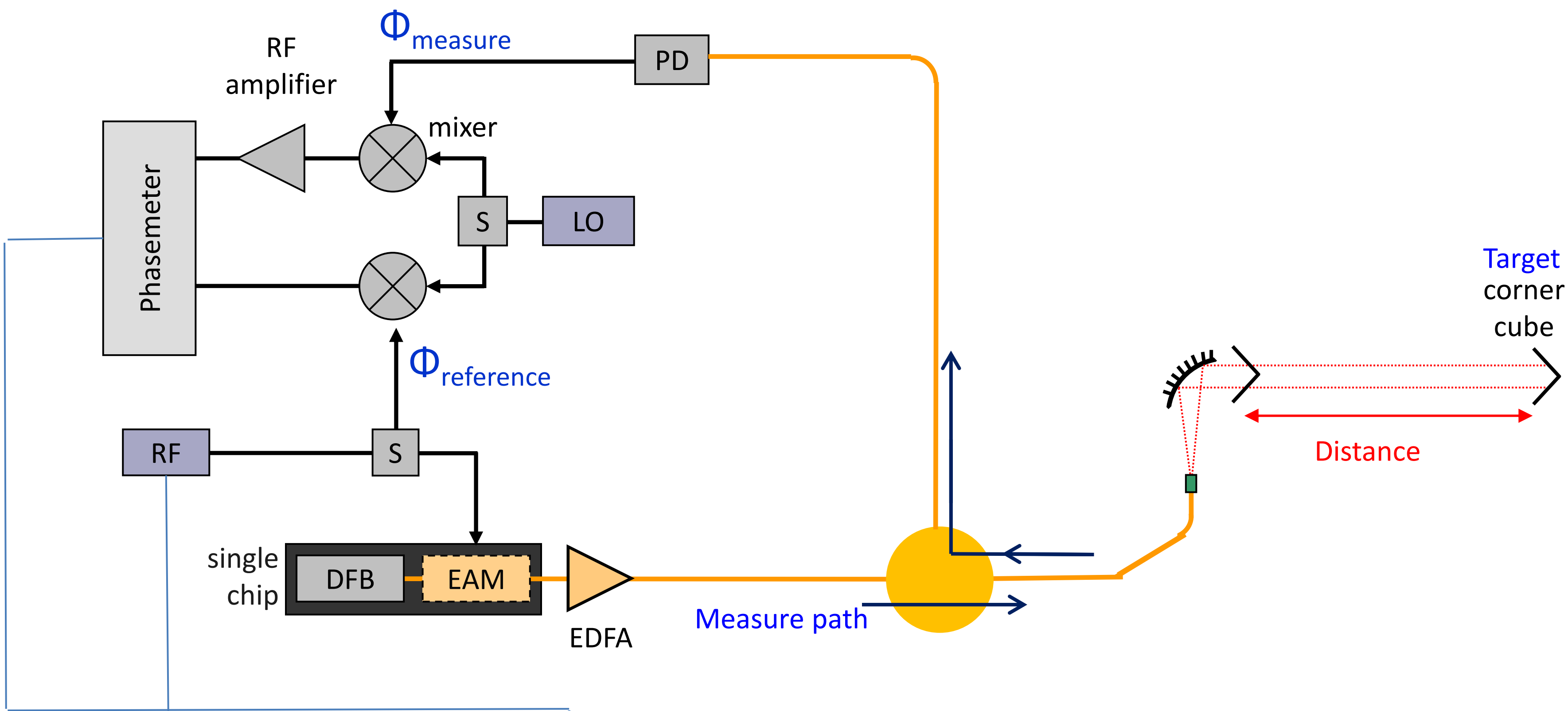
CNAM: This talk

First step: a telemeter at 1550nm

Why this wavelength?
Large availibility of any fiber component at relatively low cost
- A posteriori a great advantage for validating or not different technical options

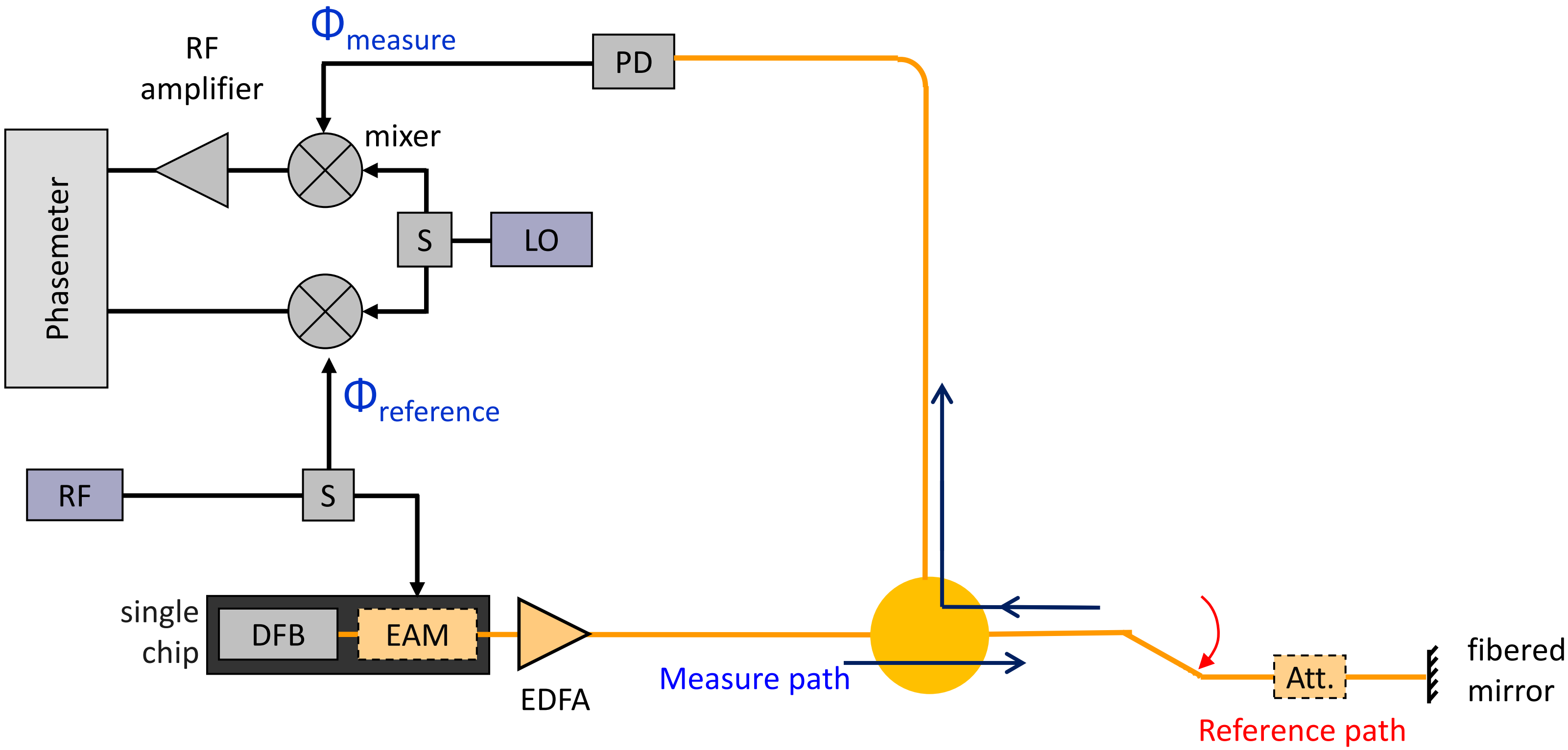
le cnam

Experimental setup at 1550nm

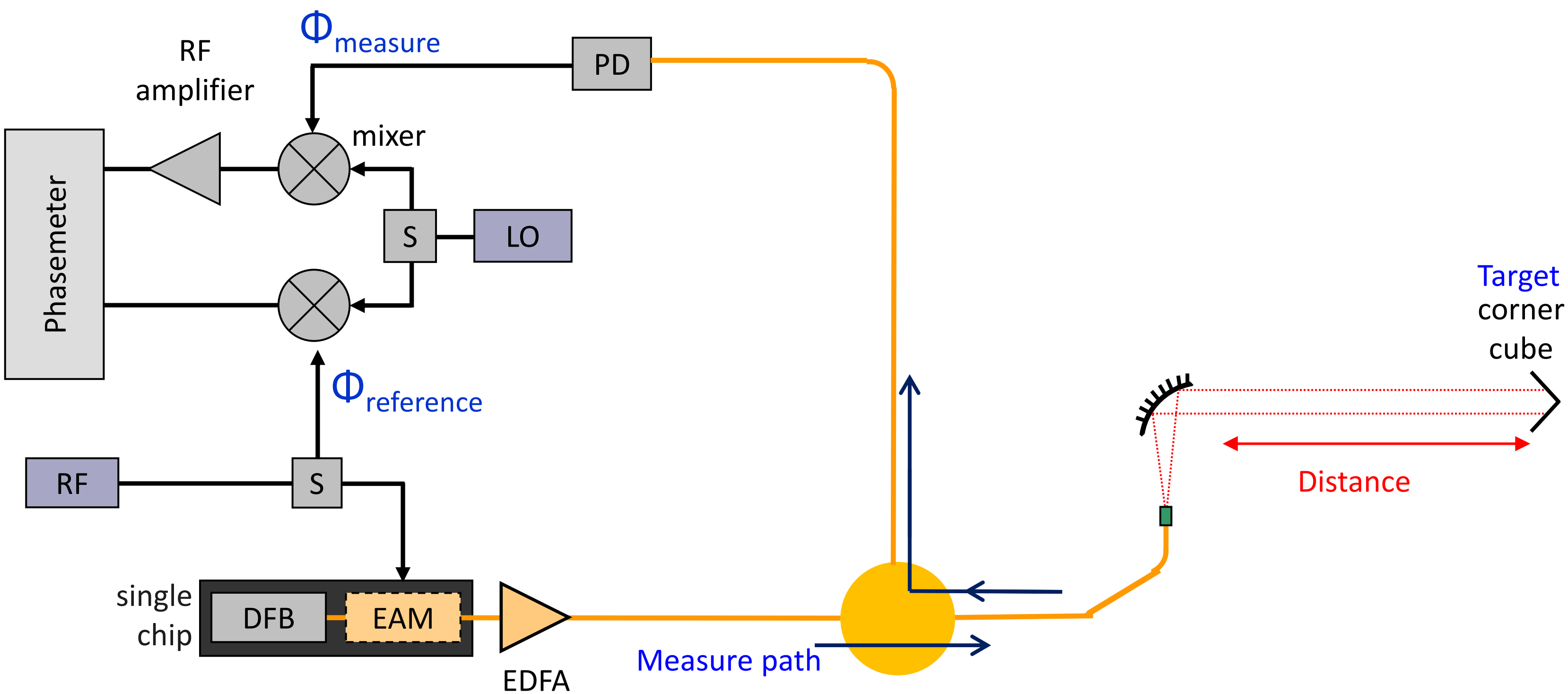


$$L = \frac{1}{2} \times \frac{\phi_{(rad)}}{2\pi} \times \frac{c}{n_{air} \cdot f_{RF}}$$

Experimental setup at 1550nm

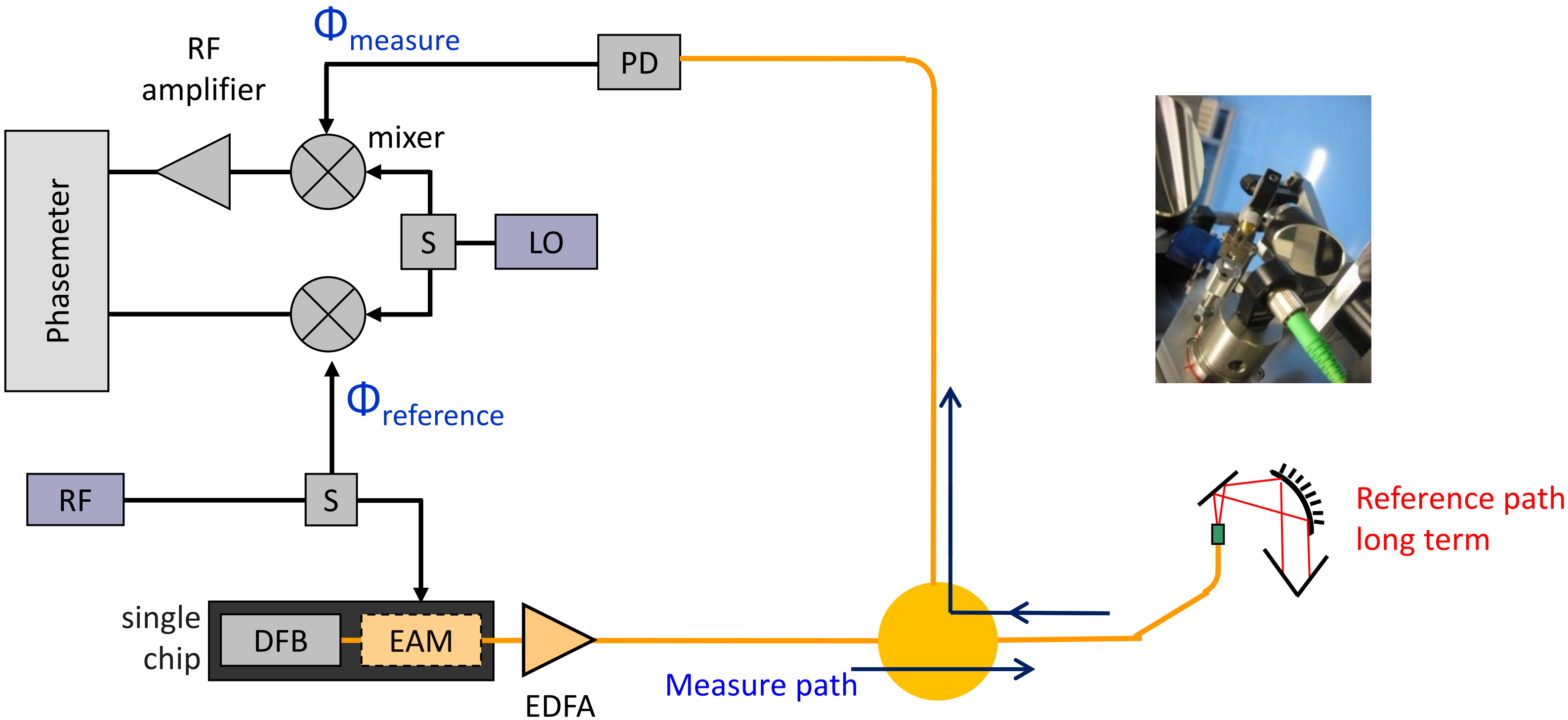


Experimental setup at 1550nm



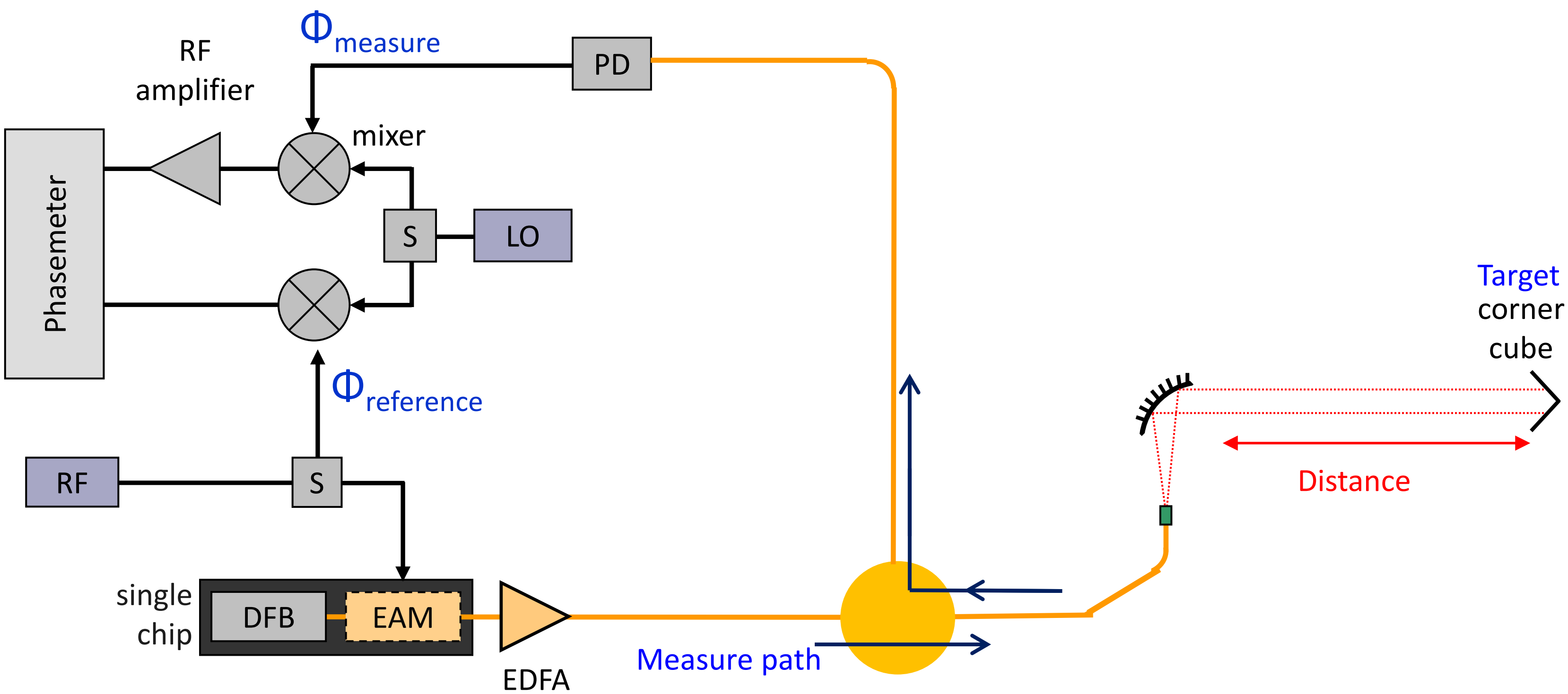
le cnam

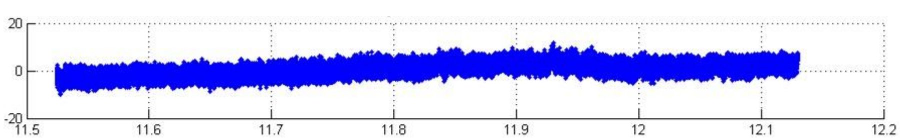
Experimental setup at 1550nm



le cnam

Experimental setup at 1550nm

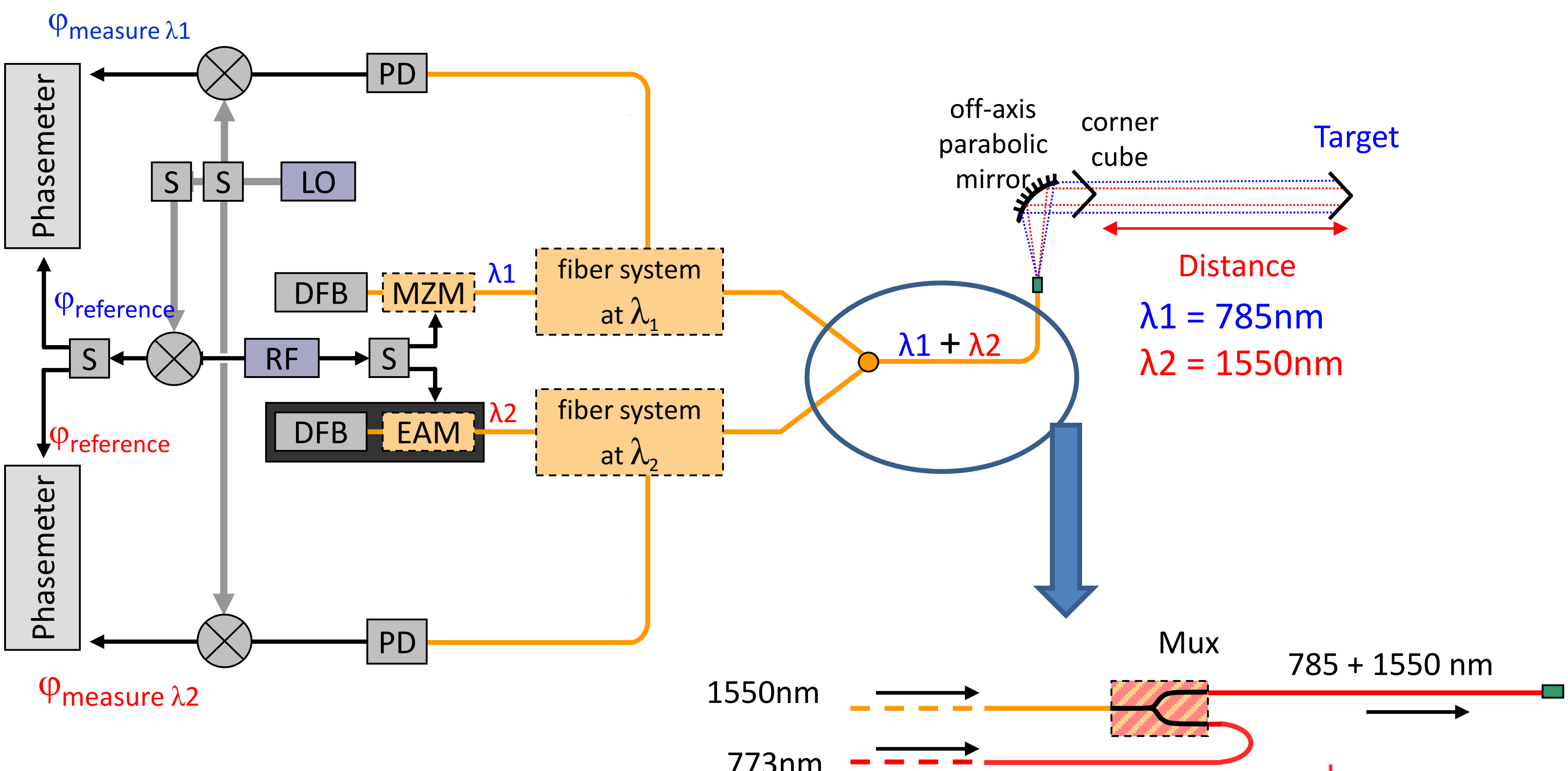




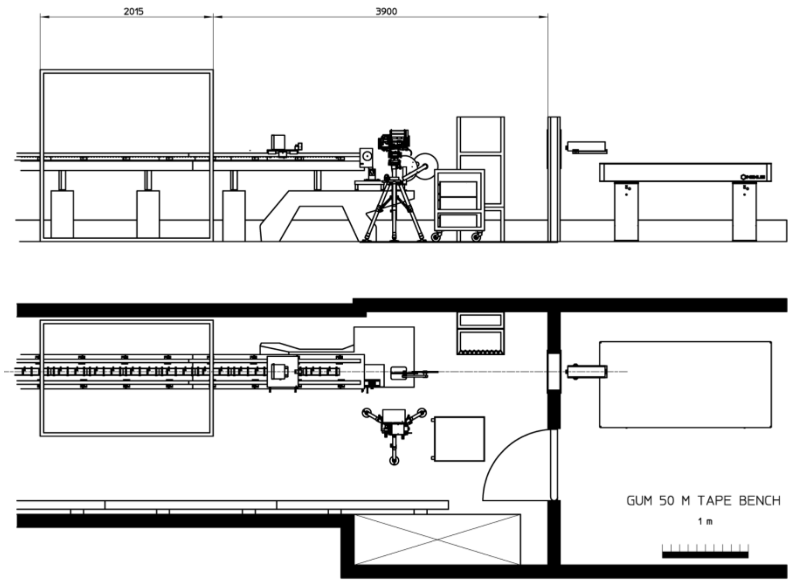
Indoor stability over half an hour (50 m)

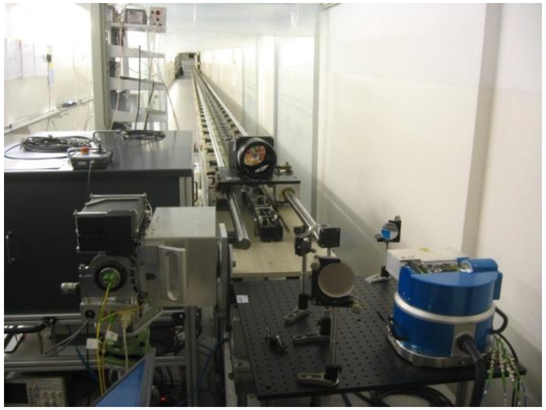
Resolution around 2 µm in quiet environment

Accuracy at the same level indoor up to 50 m:
No non linearities detected, strong reduction of electronical and optical cross talks

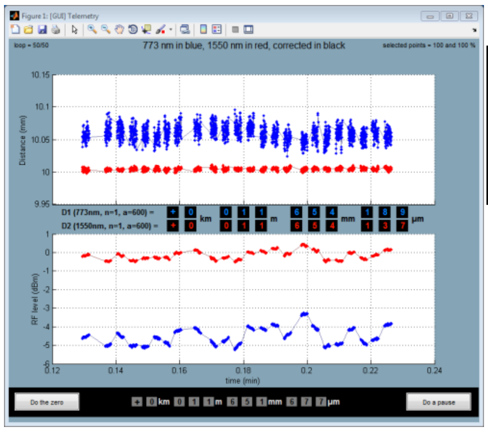

φmeasure λ1
Phasemeter
PD
S
S
LO
φreference
S
RF
S
DFB
MZM
λ1
fiber system at λ_1
DFB
EAM
λ2
fiber system at λ_2
φreference
Phasemeter
PD
φmeasure λ2
λ1 + λ2
off-axis parabolic mirror
corner cube
Target
Distance
λ1 = 785nm
λ2 = 1550nm
Mux
785 + 1550 nm
1550nm
773nm

Results of comparison at GUM (Poland)



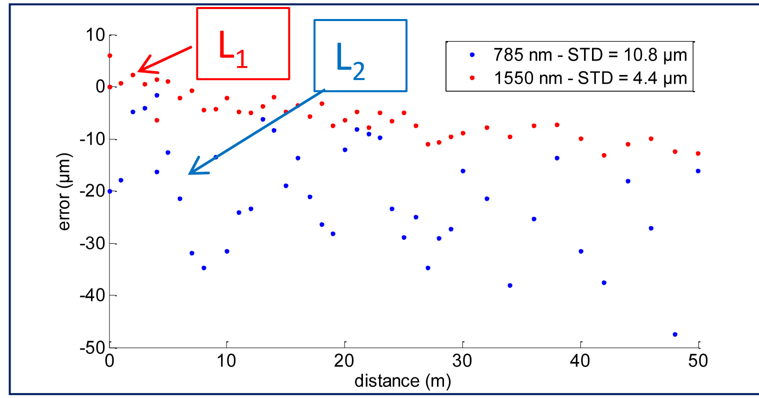


Results of comparison at GUM



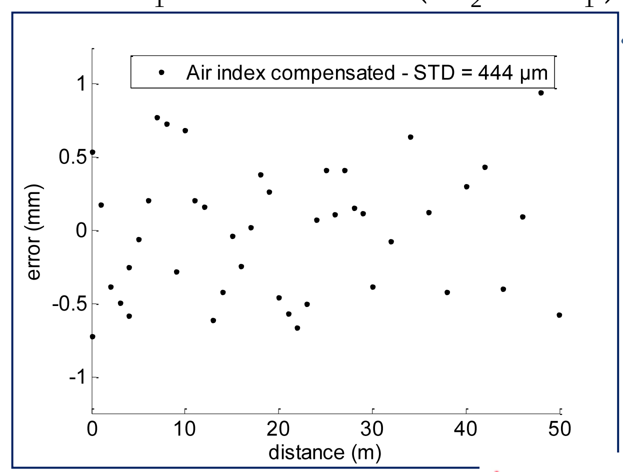
Resolution :

2.0 µm @ 1550 nm
11.2 µm @ 785 nm



We observe slope errors of 17 µm over 50 m at 785 nm and of 14 µm at 1550 nm. Without these slope errors, the standard deviation are : 9.5 µm at 785 nm and 2.1 µm at 1550 nm.

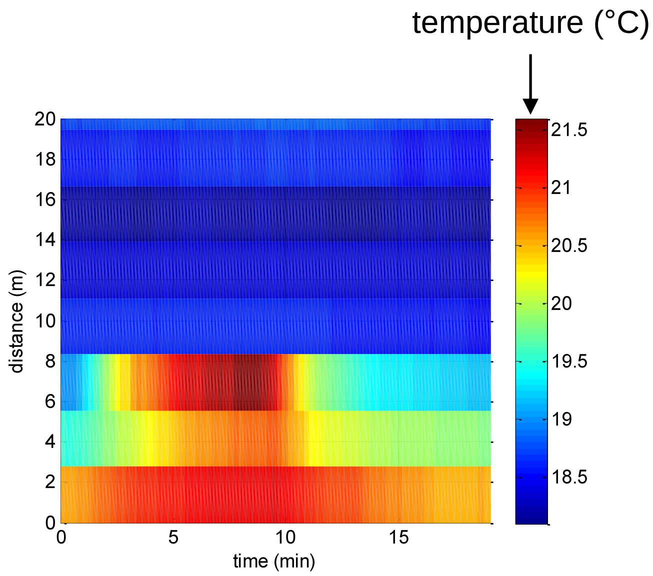
$$L = L_{0_1} - A(\lambda_1, \lambda_2)\left(L_{0_2} - L_{0_1}\right)$$

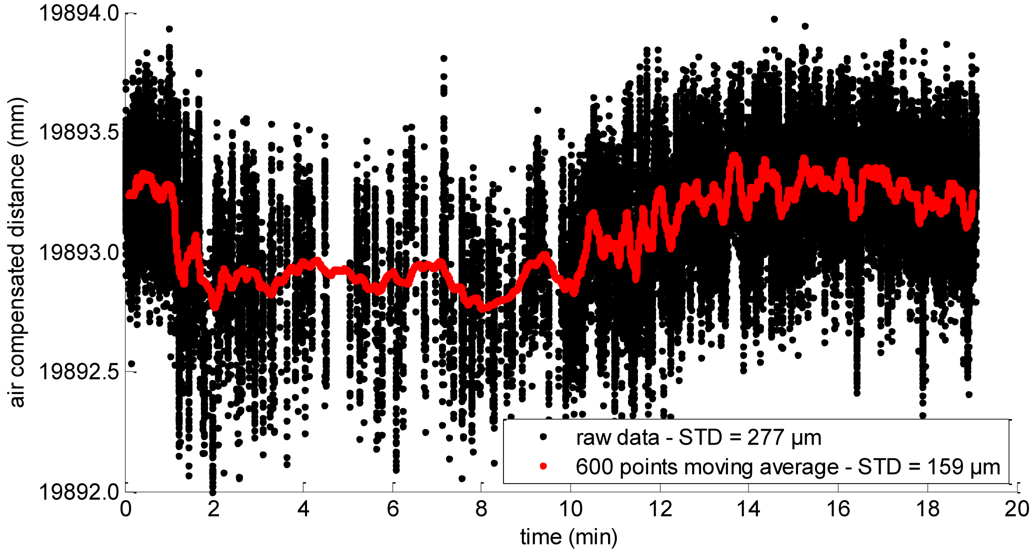


A std of 450 µm is obtained , compatible with 11 µm obtained for the std at 785 nm.

The distance is determined without any knowledge of air temperature and pressure

Stability of the measurement with temperature gradient



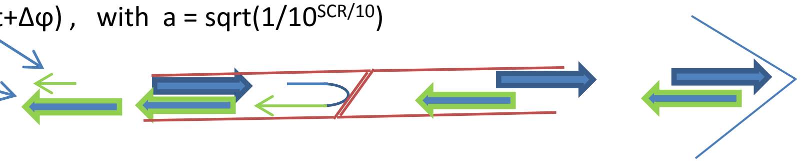


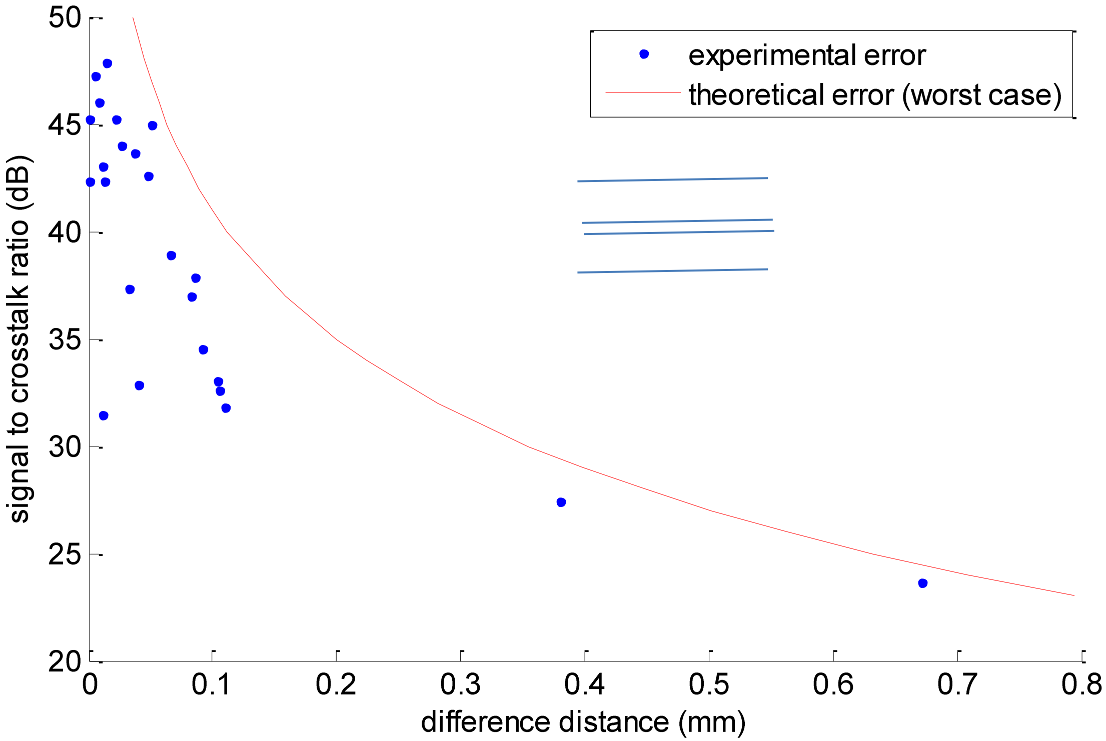
Main source of error:
optical feed back due to fiber-to-fiber reflection

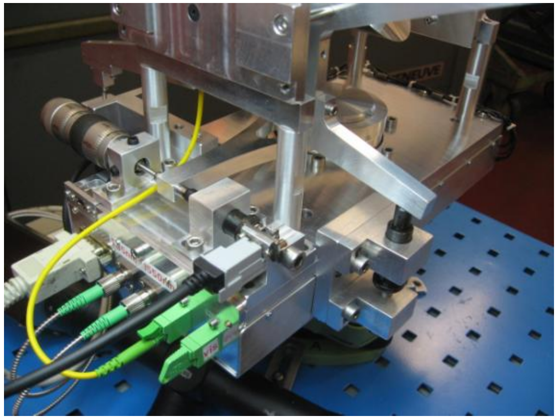
signal without crosstalk = $\sin(2\pi f_0 t)$

signal with a crosstalk = $\sin(2\pi f_0 t) + a \cdot \sin(2\pi f_0 t + \Delta\varphi)$,   with $a = \mathrm{sqrt}(1/10^{SCR/10})$

The error is maximized when $\Delta\varphi = \pi/2$

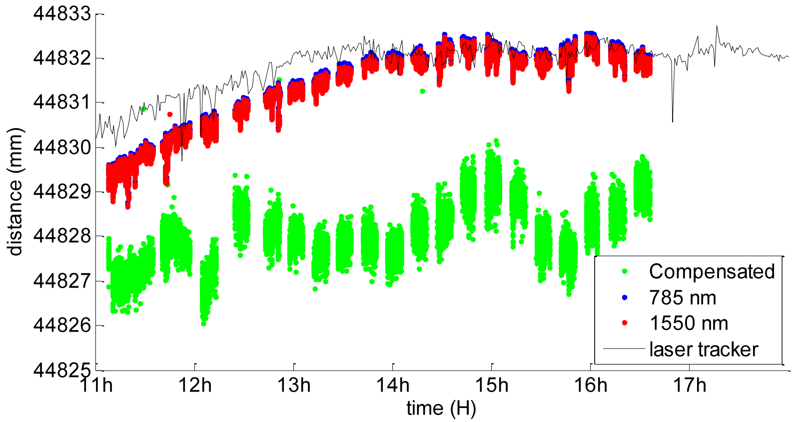


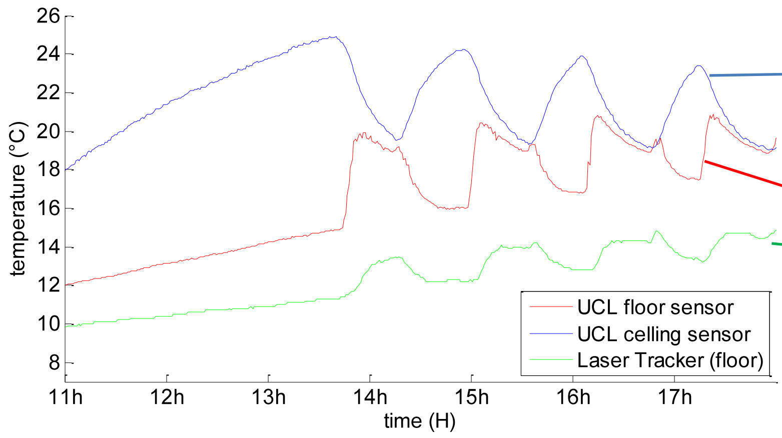


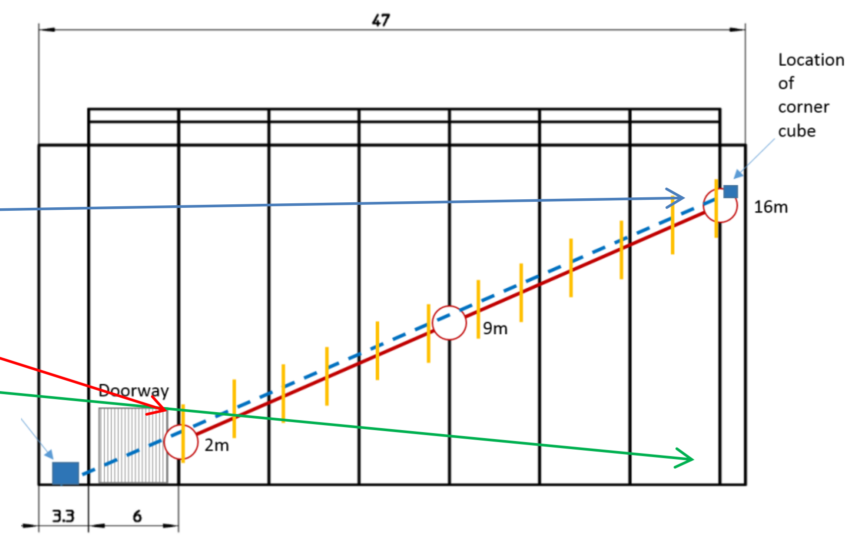


With new fibers: we can get 80 dB of SCR.
But it can evolve up to 45-50 dB after several deconnections/reconnections.

Test at airbus







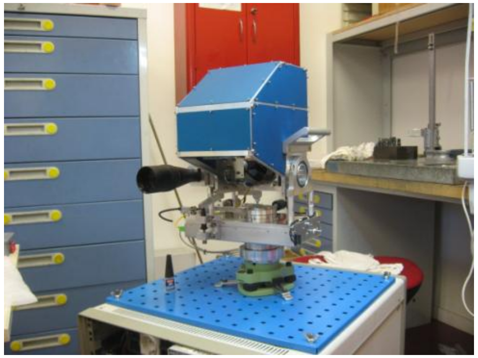
Conclusion

- At 1550 nm we have demonstrated an ADM operation with 2 µm resolution and accuracy very close to this value
- The system is very robust and compact, based on all-fiber technology.
- Resolution and accuracy of the second wavelength (785 nm) is 5 times worse
- Nevertheless an air index compensation at 500 µm was demonstrated over 50 m
- Great sensivity of the accuracy system to inter-fibers connections → fusion splicing and no deconnection/reconnection of fibers.

How to go further ?

- Using the same optical head and electronics but changing wavelength: 1064/532 nm → Amplification factor of 20 instead of 50 (work ongoing)
- An accuracy of 100 µm is a reasonable target
- Validity of air index modeling (dispersion of air) should be improved at specific wavelengths

THANK YOU FOR YOUR ATTENTION



EMRP
European Metrology Research Programme
Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

le cnam