

ACES microwave link-related activities at the National Physical Laboratory

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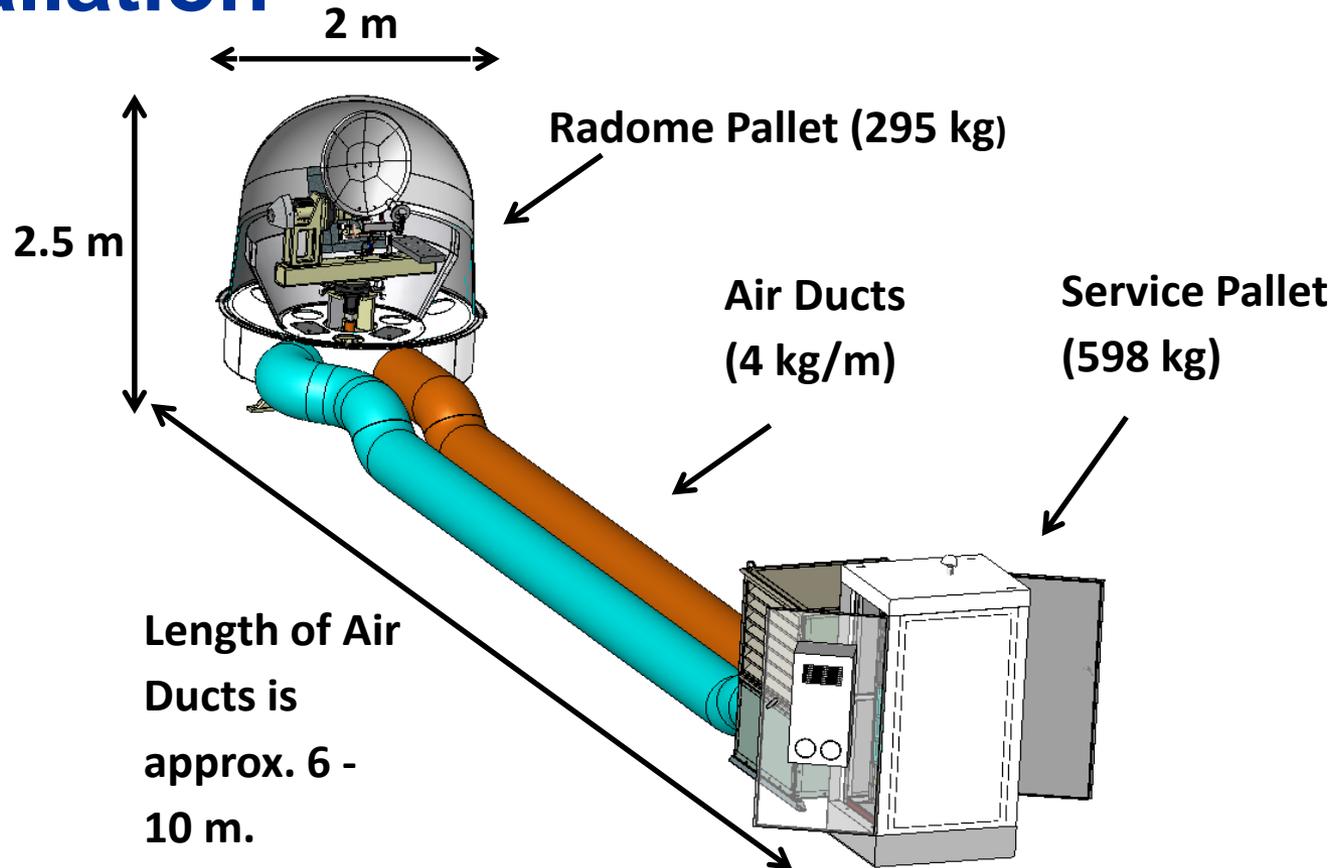
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Introduction

- Infrastructure at NPL for input to ACES
- Optical clocks
 - Sr⁺ ion optical clock
 - Yb⁺ ion optical clock
 - Sr lattice clock
- Caesium fountains
 - NPL-CsF2
 - NPL-CsF3
- Frequency combs
- UTC(NPL)
- Optical fibre link connecting NPL to SYRTE-PTB

2. Plan for ACES MWL ground terminal installation



NPL Modules and B47



Loading/multipath
issues for modules



B47 -
location of
van de
Graaff
accelerator

Microwave background level interference limits (from ESA)

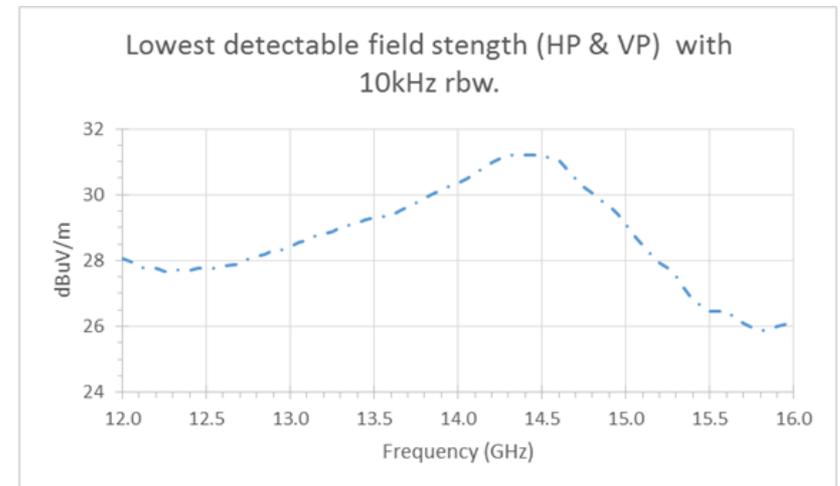
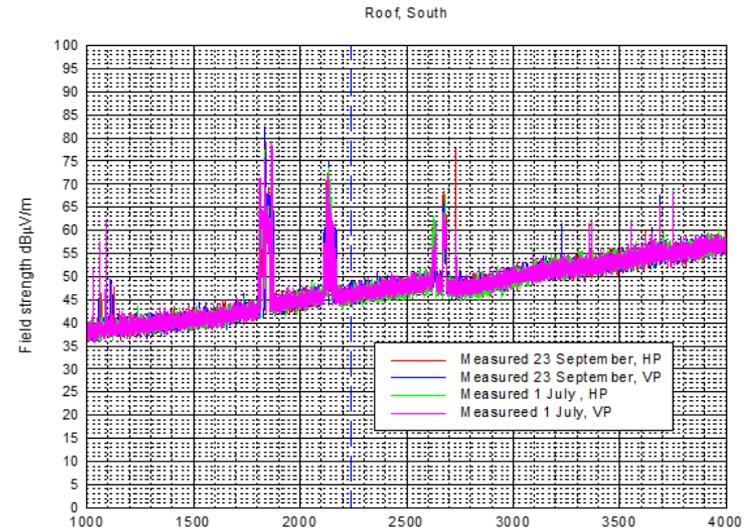
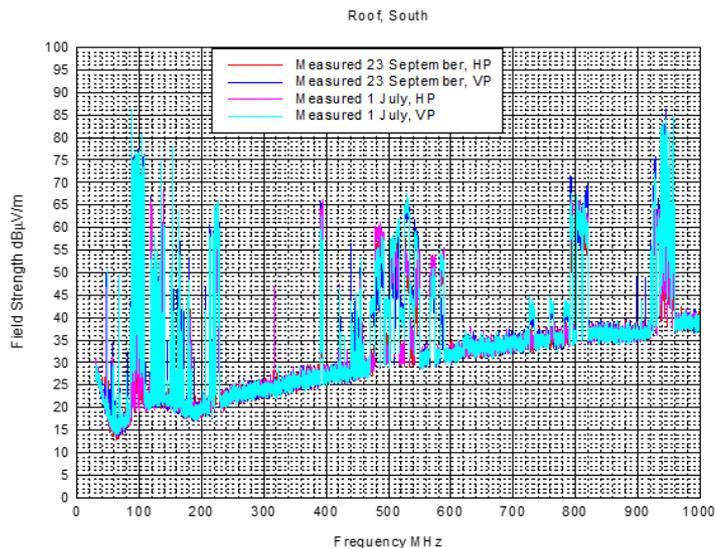
The MWL GT is operational at full performance with external interferers not exceeding following limit level.

Frequency [GHz]	Limit [V/m]
1.0 - 1.6	870
1.6 - 2.0	11
2.0 - 2.17	0.68
2.17 - 2.3	6.8E-6
2.3 - 2.4	4E-5
2.4 - 2.5	4
2.5 - 2.7	14
2.7 - 10	30
10 - 14.6	82
14.6 - 14.8	9.5E-4
14.8 and above	82

Table 4-1: Interference Limits

EM surveys on B47 roof (by NPL EM Measurements Group)

Test measurements taken with van de Graaff accelerator in on and off states.



3. Fibre link between the clocks and ground terminal



M4

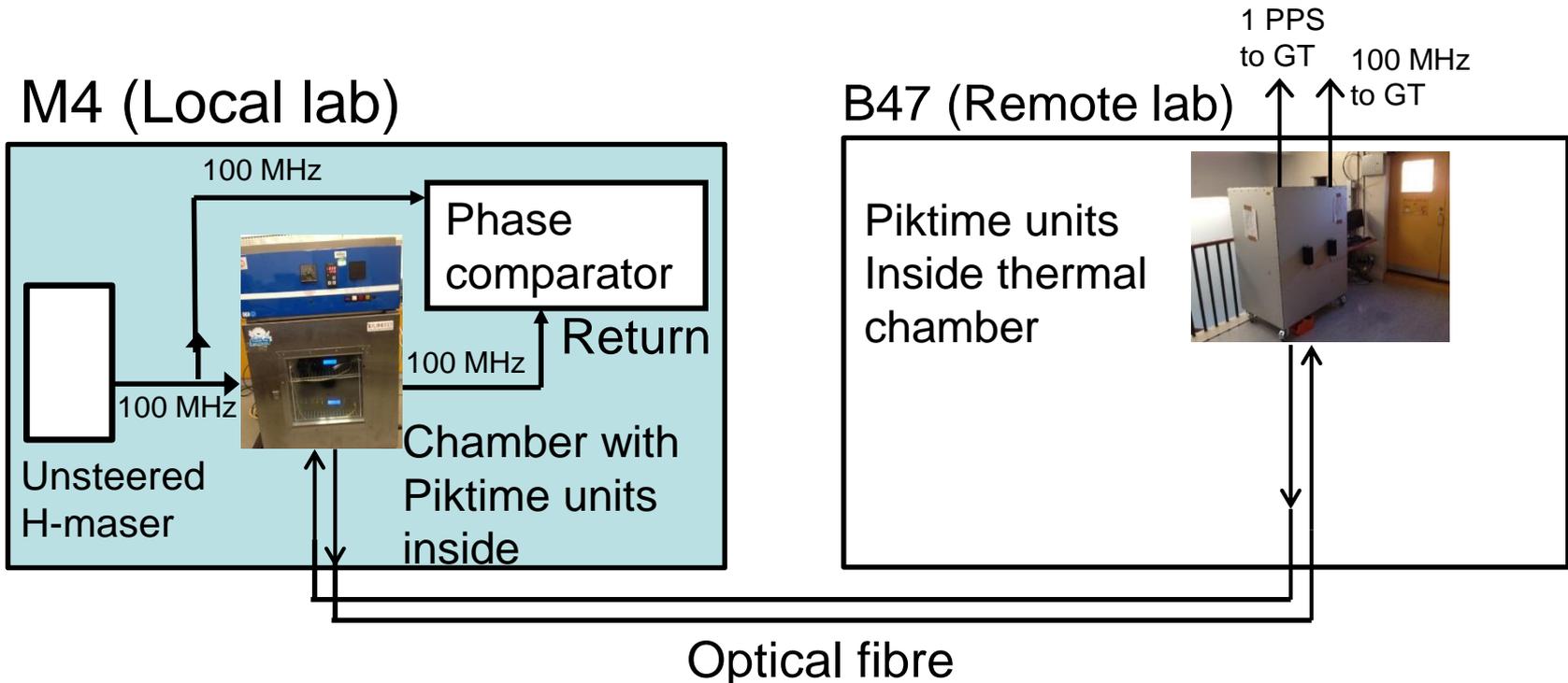


B47



Out-and-Return fibre link using 4 Piktime units

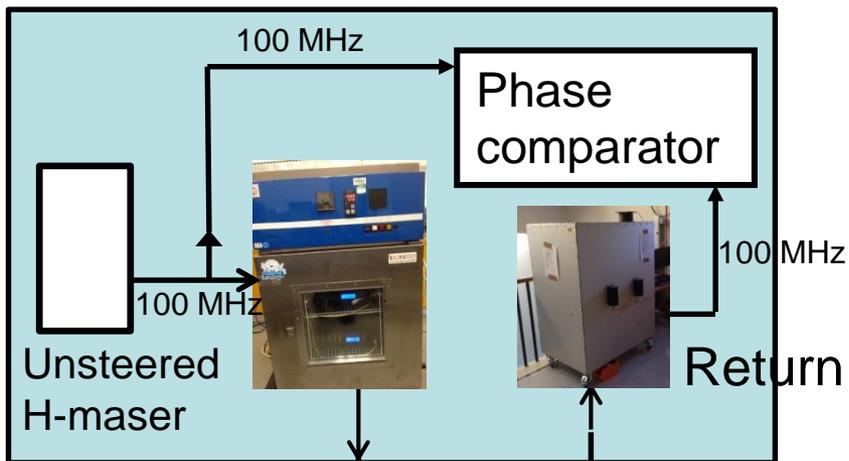
Testing with Piktime System, loaned from AGH university. Used one local and one remote unit in each of two thermal chambers and a phase comparator to compare phase difference between outgoing and return signals.



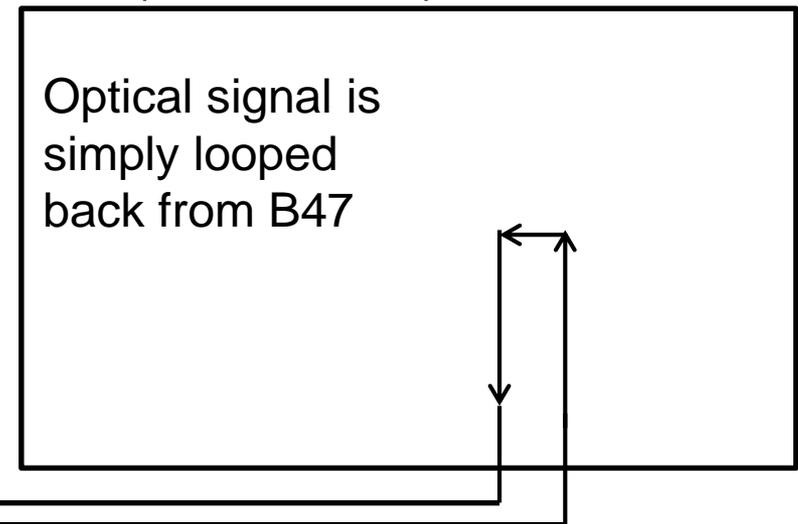
M4/B47 fibre link test using 2 Piktime units

One local unit in one chamber and one remote unit in other chamber, all in local lab in M4 using fibre loop to/from B47. Closely represents frequency stability of a M4-B47 link.

M4 (Local lab)

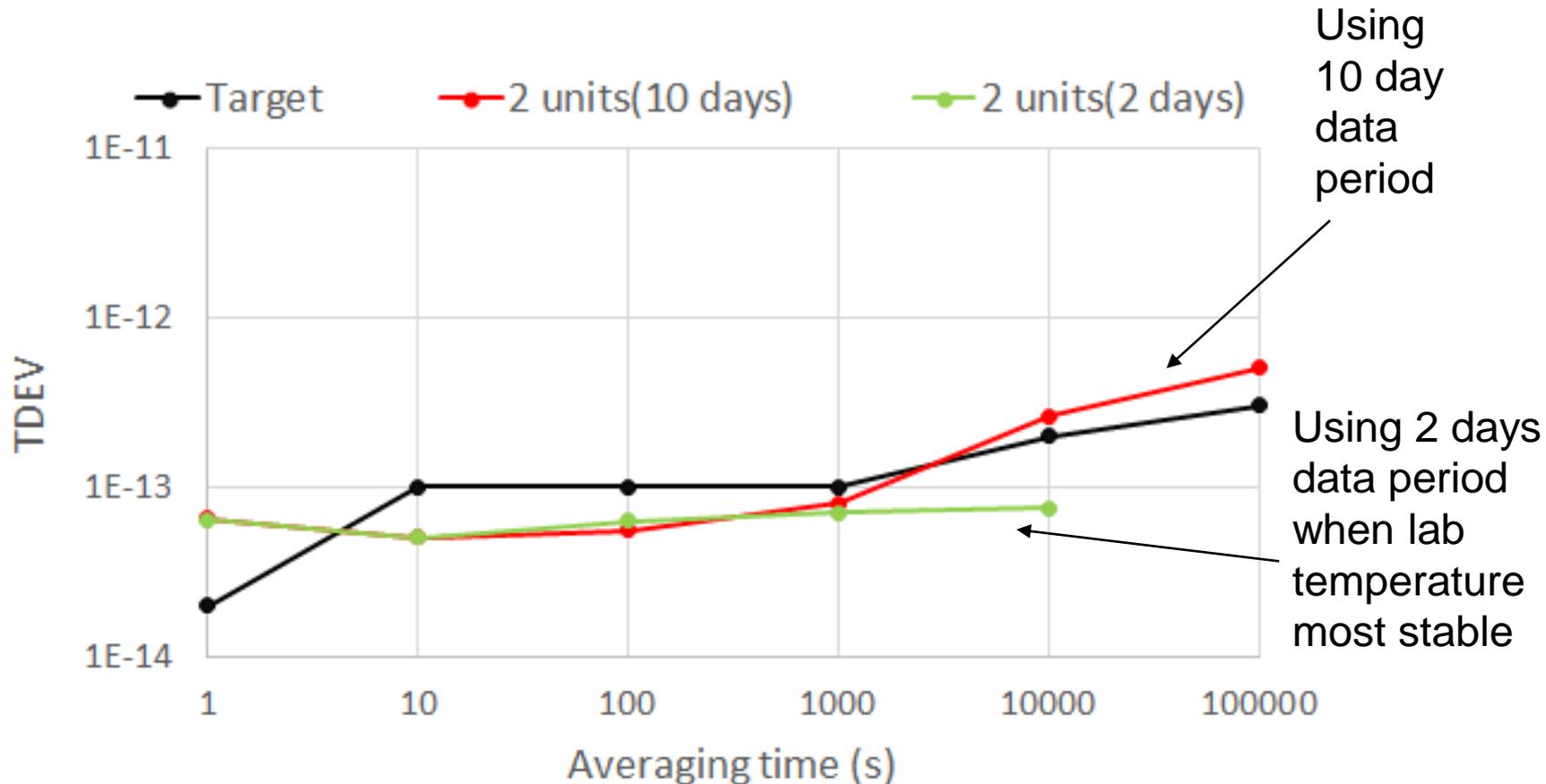


B47 (Remote lab)



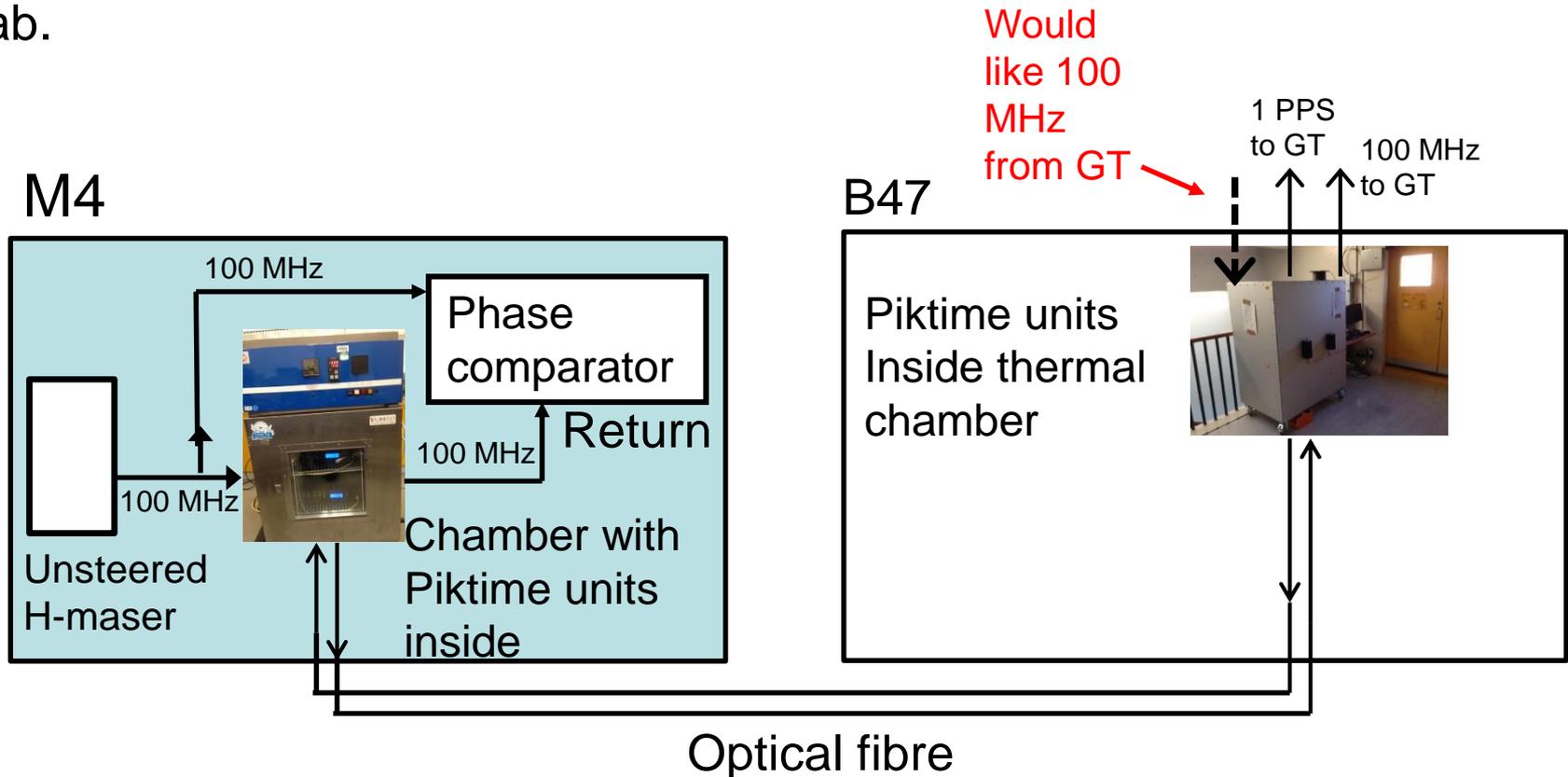
Optical fibre

Fibre link target and actual system performance (2 units)



Out-and-Return fibre link using 4 Piktime units

Ideally, if possible (it may not be), would like a reference 100 MHz output signal from the ground terminal and this be returned to the local lab.



4. Analysis of ACES microwave link data

Objectives

- A 1–year ‘Fast-track’ R&D project funded by the UK Space Agency and the UK National Measurement System to investigate analysis methods for exploiting MWL data.
- Limited what can be achieved in 1–year – aim is to do research into the MWL system and physical effects and to develop prototype algorithms – to investigate navigation and time/frequency transfer.
- We are not implementing a fully operational data processing software which would need a lot more time and effort.
- Prototype algorithms also being developed for simulating ACES MWL output data in order to test the analysis algorithms.

Analysis of ACES microwave link data

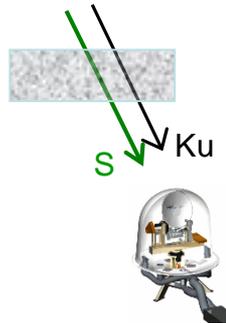
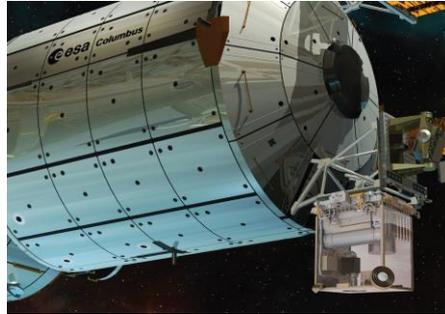
Simulation – Matlab/Python

Analysis – Matlab

Currently in process of research/development of underlying algorithms for one-way signal simulation/analysis

- Simulation of Flight Segment and ground terminal positions/relative motion
- Doppler shift
- Relativistic effects
- MWL beatnote signal, using integration of signal frequency to estimate accumulated code and carrier phase at receiver (*small dt increments – long computation times*)
- Ionosphere delay (and potentially troposphere delay)
- Code integer ambiguity resolution

Analysis of ACES microwave link data



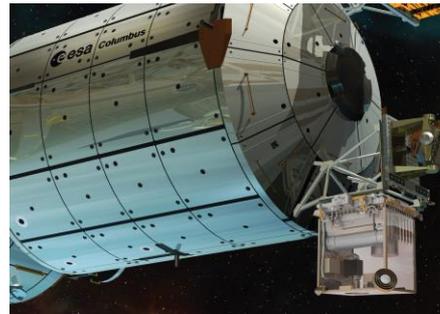
Δt delay due to ionosphere
changes little over a second, but
a lot more over longer intervals.

Prototype algorithms to investigate potential future GNSS performance using improved space clocks. Use of integrated Doppler measurements of downlink signals will be investigated.

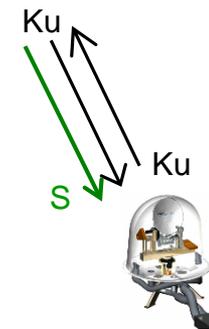
Analysis of ACES microwave link data

Later aim to investigate two-way time/frequency transfer analysis

- Two-way signal combinations (using so-called lambda-configuration)
- First-order Doppler correction



Prototype algorithms for two-way analysis of signals to compare time/frequency between space and ground clocks.



Analysis of ACES microwave link data

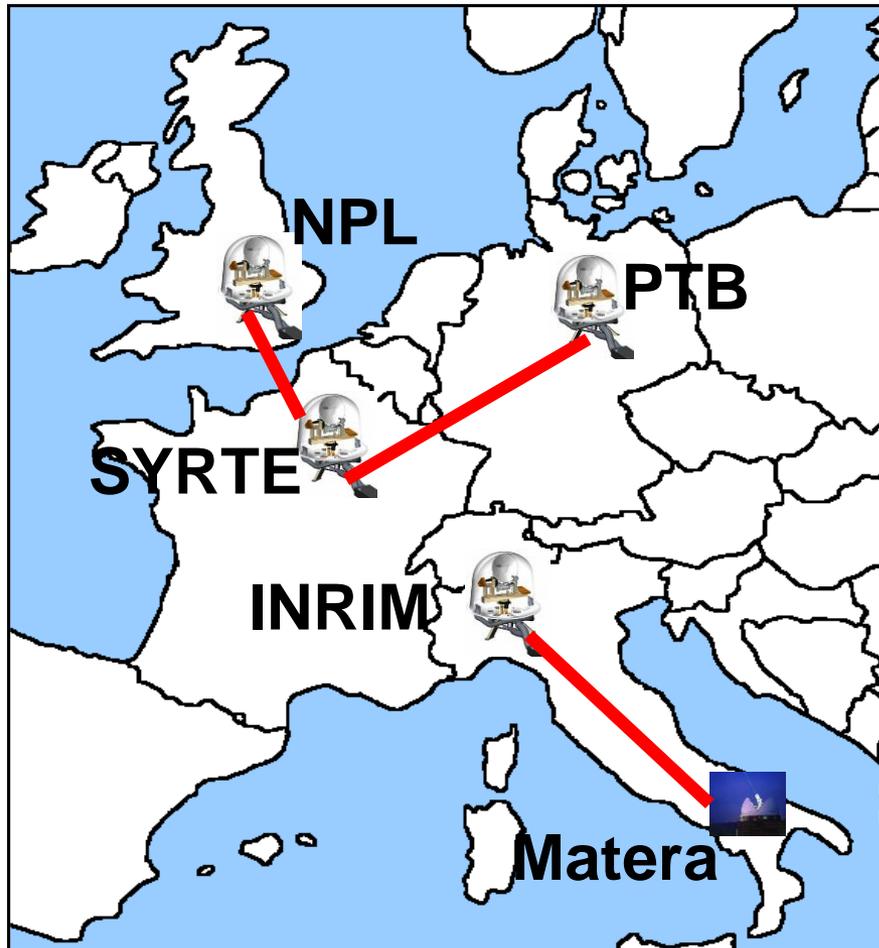
Present limitations/challenges

- Need more MWL system information i.e. computational data flow – what data (incl. corrections/calibration data) will be available at what stage to combine in the analysis
- Long computation times
- Calculation precision (machine error)
- No consideration yet of a number of factors eg

carrier-phase ambiguity resolution, antenna phase centre delays, calibration delays, multipath, clock noise, solar radiation pressure

A follow-on project will be needed to continue developing the algorithms produced and to exploit these during ACES operations

5. Tests of the ACES MWL using fibre links in Europe



In the EMPIR OFTEN Project, there is a task to validate the performance of the ACES MWL.

This will be a critical first step for understanding performance of intercontinental ACES links.

Summary

- NPL and ESA are preparing for installation of an ACES ground terminal at NPL.
- We have tested a commercial optical fibre transfer system to connect NPL's clocks and the MWL ground terminal.
- A 1-year project is underway to research/develop prototype algorithms for analysis/simulation of ACES MWL data.
- An experiment is being planned to validate the ACES MWL using fibre links between European NMIs, within the OFTEN EMPIR project.