Status of fibre optic links at NPL

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GEANT SIG-TFN technical

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Agenda

Introduction & Geographical overview

Birmingham link

1. Setup and signals on the link

2. Link Setup

3. Link monitoring

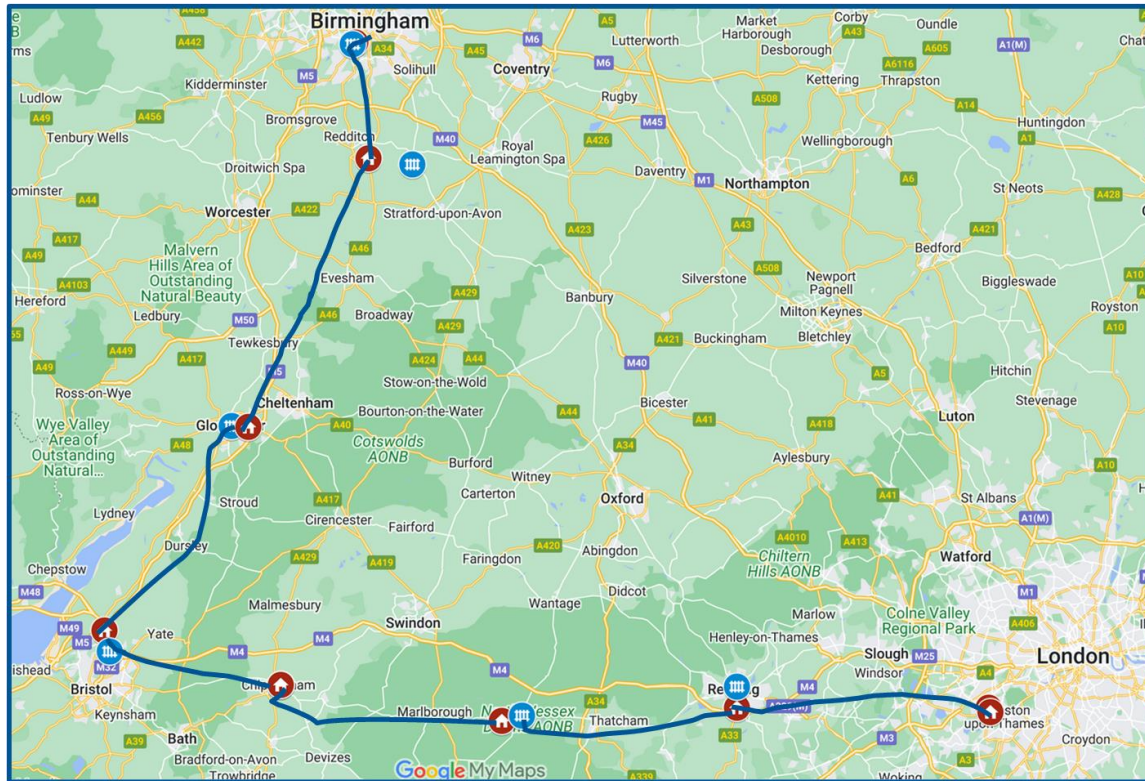Conclusion and future work

Introduction & purpose

Why fibre links?

- **Research**: Currently NPL (and others NMIs, Universities) are developing optical atomic clocks, but these are only compared with European partners on a sporadic basis (typically once a year).
  - > Need for more distributed development and ability to compare clocks more regularly, particularly considering the SI second redefinition.

- **Infrastructure**: *Resilience* > GNSS is vulnerable to external threats such as Jamming, Spoofing, Meaconing but also environmental changes. All these are discussed in detail in the Blackett review. Optical fibre links are one way of building resilience in T&F dissemination.

- **Future Industry**: The current Frequency standard based on Caesium fountains has a performance that is at least 1 order of magnitude worse than Optical atomic clocks, interest in WR, PTP.

NPL Fibre Links Overview

NPL-Paris
- ❖ 2 dark fibres
- ❖ 10 colocations
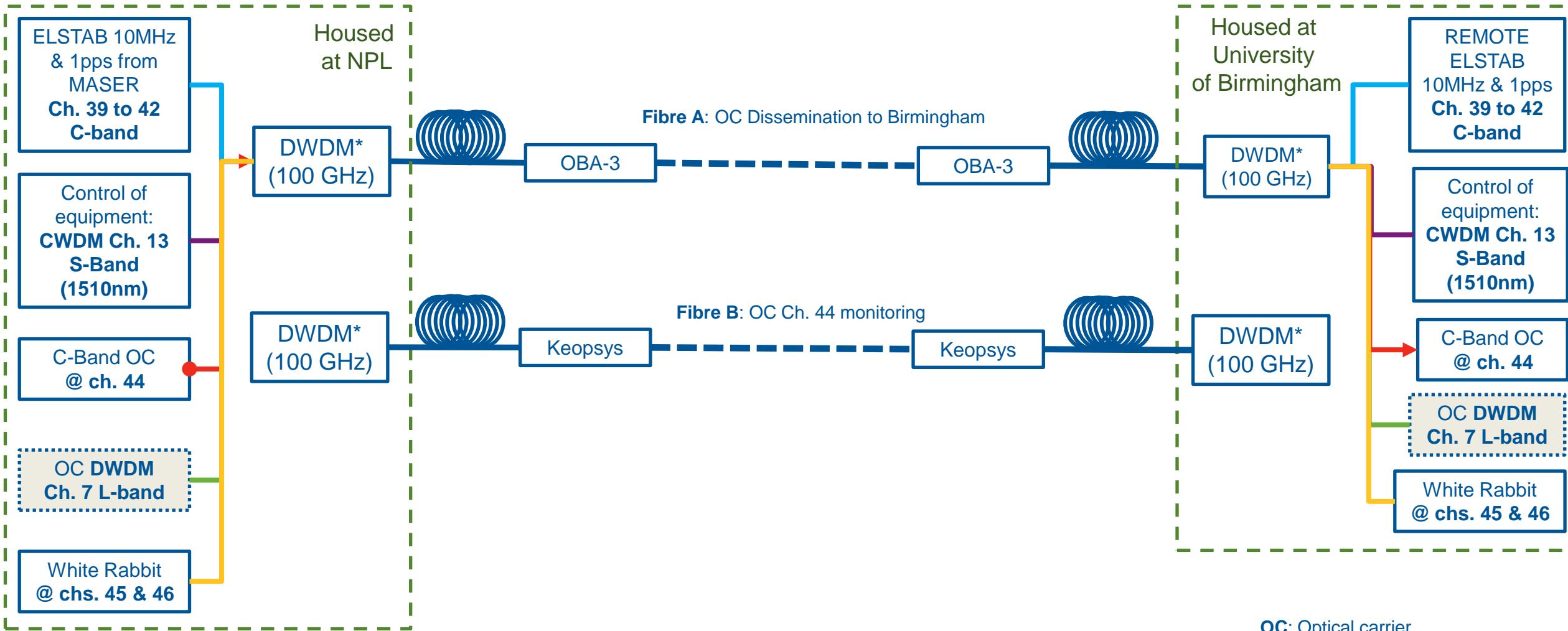- ❖ Fibre length: ~ 760km *2

NPL-Birmingham
- ❖ 2 dark fibres
- ❖ 6 colocations
- ❖ Fibre length: ~ 380km * 2

Birmingham link overview

Fibre length c. 380km x 2)

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Housed at NPL

- ELSTAB 10MHz & 1pps from MASER **Ch. 39 to 42 C-band**
- Control of equipment: **CWDM Ch. 13 S-Band (1510nm)**
- C-Band OC **@ ch. 44**
- OC **DWDM Ch. 7 L-band**
- White Rabbit **@ chs. 45 & 46**

DWDM* (100 GHz)

DWDM* (100 GHz)

OBA-3 — — — OBA-3

Fibre A: OC Dissemination to Birmingham

Keopsys — — — Keopsys

Fibre B: OC Ch. 44 monitoring

Housed at University of Birmingham

DWDM* (100 GHz)

DWDM* (100 GHz)

- REMOTE ELSTAB 10MHz & 1pps **Ch. 39 to 42 C-band**
- Control of equipment: **CWDM Ch. 13 S-Band (1510nm)**
- C-Band OC **@ ch. 44**
- OC **DWDM Ch. 7 L-band**
- White Rabbit **@ chs. 45 & 46**

OC: Optical carrier
CWDM: 20nm spacing
DWDM: 0.8nm (100GHz) spacing

*DWDM: Dense Wavelength Division Multiplexing (The term **OADM**, Optical Add Drop Multiplexer is also used). The 100GHz refers to the channel spacing.

Signals on the NPL- Birmingham link
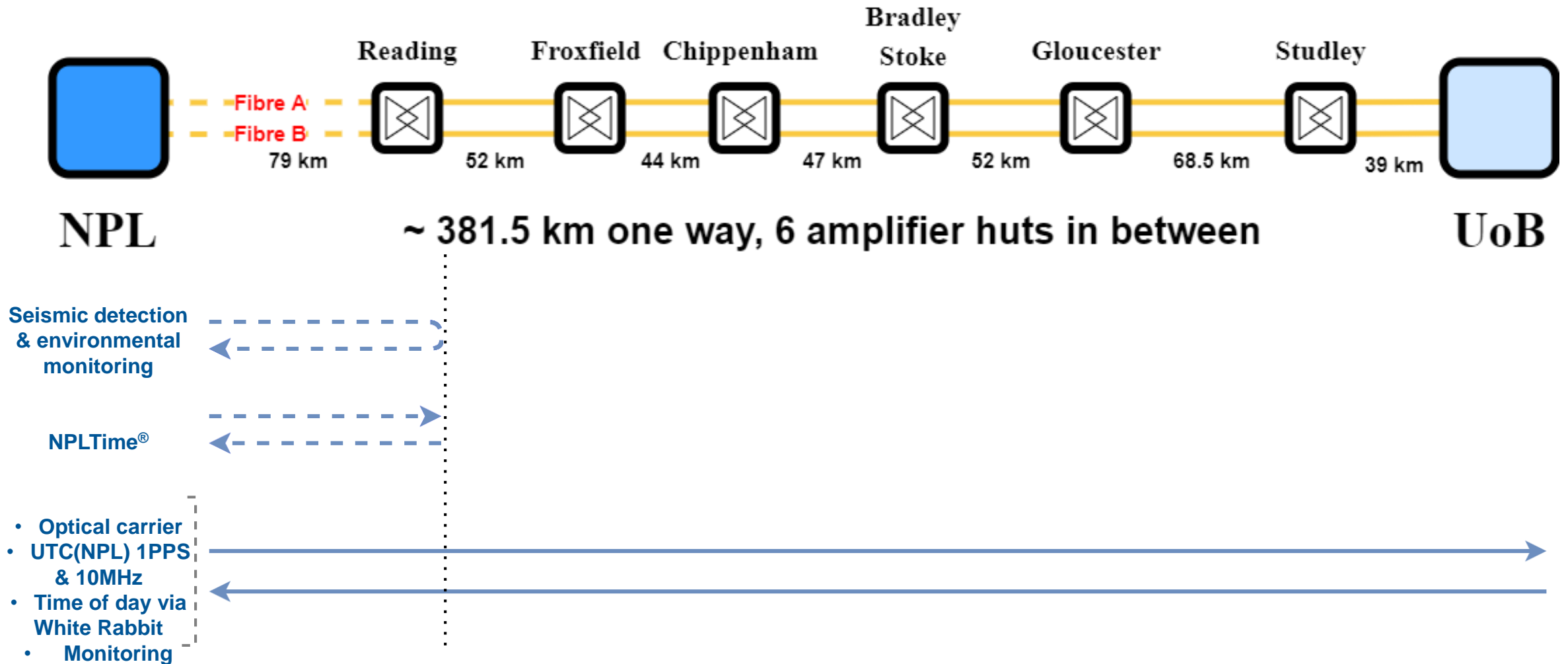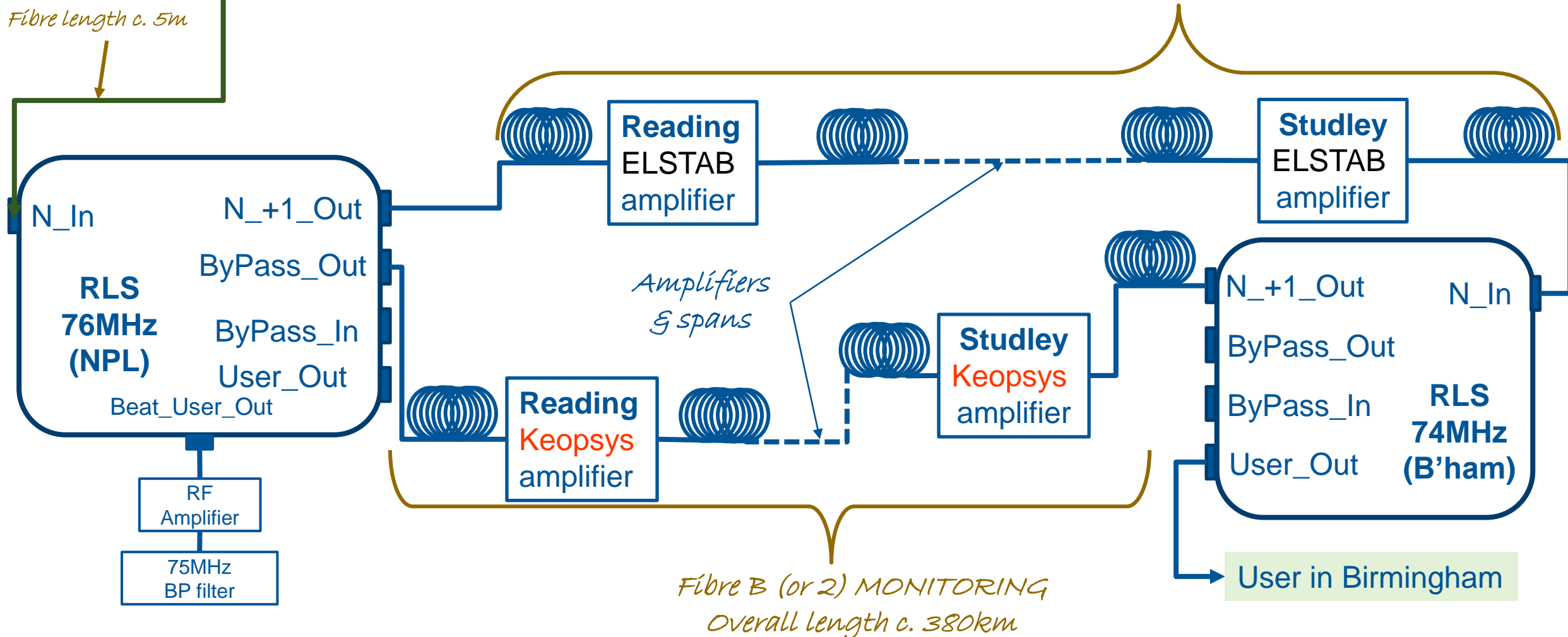

All signals share a **fibre pair** based on Dense Wavelength-Division Multiplexing (DWDM) technique.

Setup (OC only)

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T1 Laser locked to
1064nm ultrastable
cavity via Comb

Fibre length c. 5m

N+1 Fibre link
Fibre A (or 1) DISSEMINATION
Overall length c. 380km

Reading
ELSTAB
amplifier

Studley
ELSTAB
amplifier

N_In

N_+1_Out

ByPass_Out

ByPass_In

User_Out

Beat_User_Out

**RLS
76MHz
(NPL)**

*Amplifiers
& spans*

Reading
Keopsys
amplifier

Studley
Keopsys
amplifier

N_+1_Out

N_In

ByPass_Out

ByPass_In

User_Out

**RLS
74MHz
(B'ham)**

RF
Amplifier

75MHz
BP filter

Fibre B (or 2) MONITORING
Overall length c. 380km

User in Birmingham

Colocation setup

Network architecture: linear network using switches and SFPs on monitoring channel on same fibre pair of fibres.
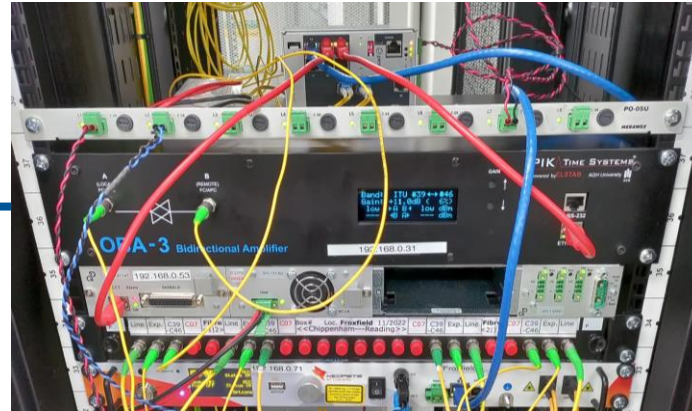

48V power supply	OBA-3 amplifier	Keopsys amplifier
IP:192.168.0.XXX	IP:192.168.0.XXX	IP:192.168.0.XXX

Towards NPL

DWDM < Line ¦ Xpress >

DWDM < Line ¦ Xpress >

Rx SFP Tx

Network Switch

Tx SFP Rx

DWDM < Xpress ¦ Line >

DWDM < Xpress ¦ Line >

Towards B'ham
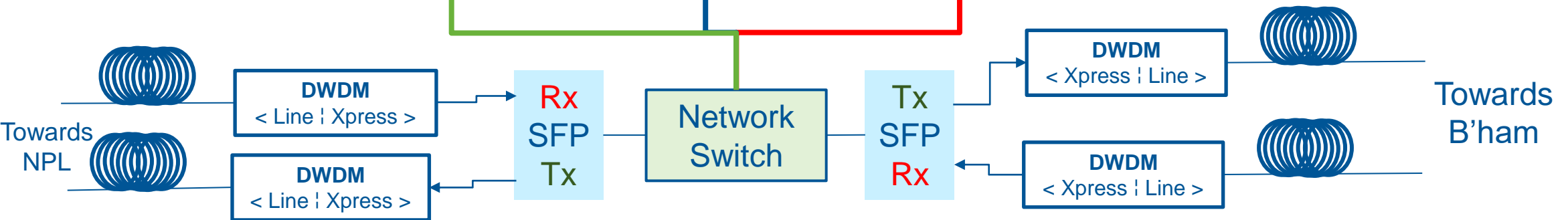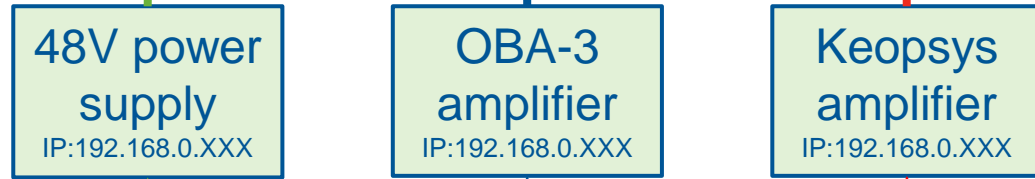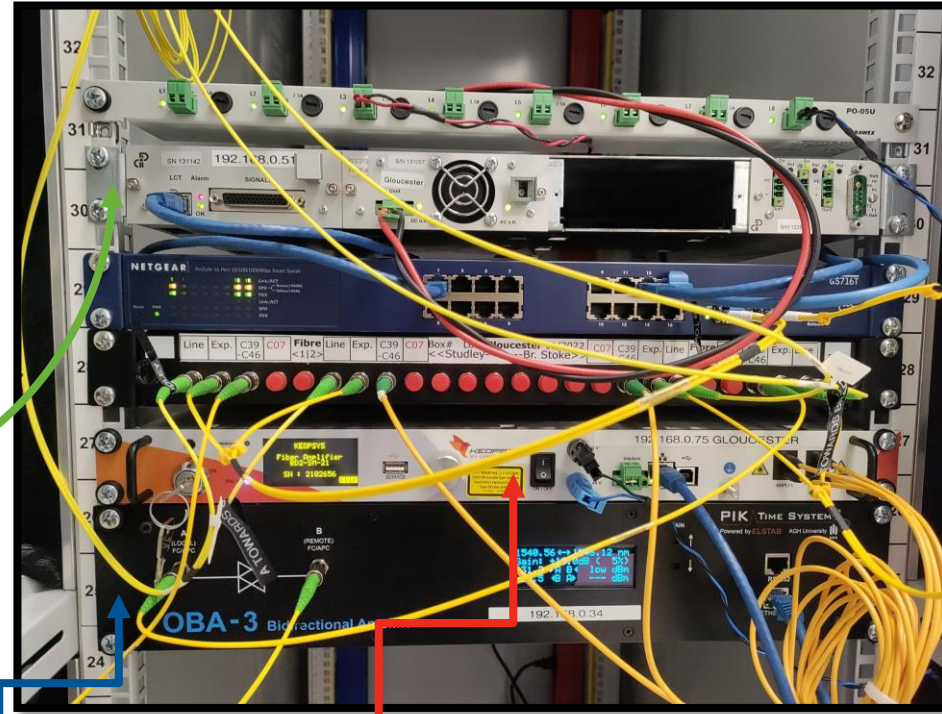
Equipment Installation at Colocations

NPL
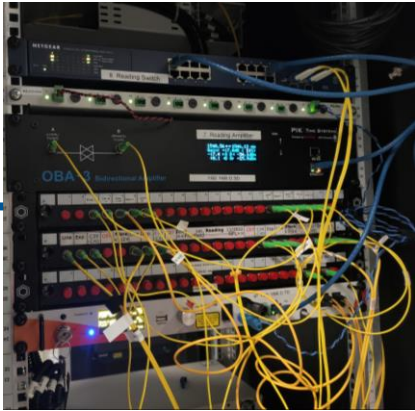
Reading

Froxfield

Chippenham

Bradley Stoke
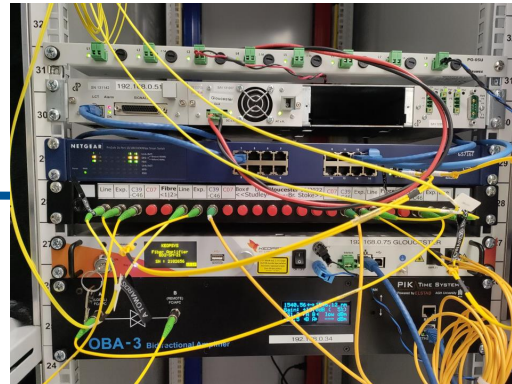
Gloucester
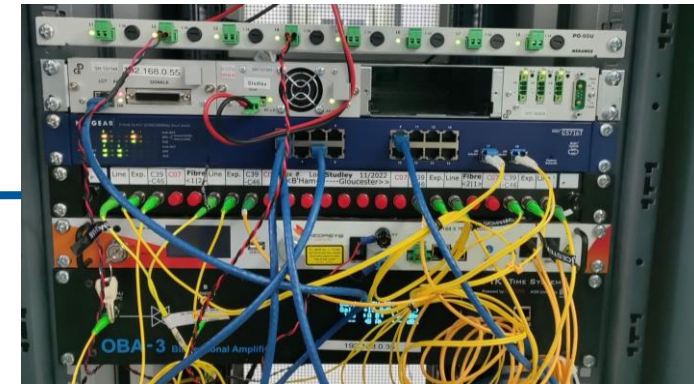
Studley

B'Ham

Link performance 7th to 15th June 2024
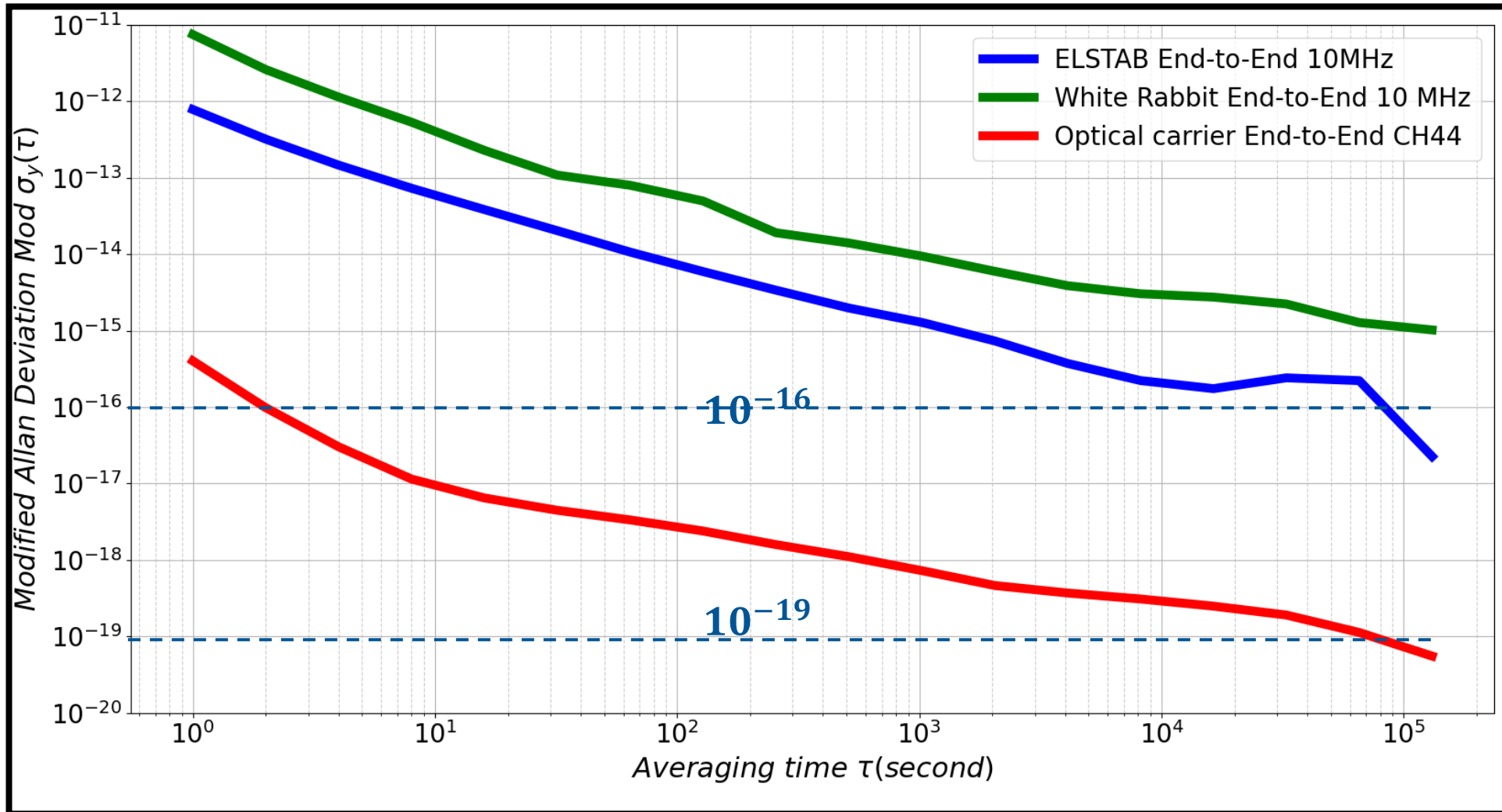
What could possibly go wrong?

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- As of October 2024, Fibre Links operating links to AQML, Birmingham and Paris, total of **20** remote sites.
- Typically, 4 to 5 instruments at each site meaning 80 to 100 different instruments to monitor and control.

Transmission medium: Fibre cuts/breaks; Power cuts; Equipment failure; Poor connection;

Stakeholder engagement: Disconnect between the "telecom" world and metrology world, different priorities, need to engage with field engineers who may not be fully aware of the type of signals we send and disseminate.

Summary: A robust Control and monitoring system is absolutely critical in ensuring a high up time.

Why Develop Remote Monitoring Software?

- Reduce response time to issues

- Improve issue localisation.

- Fix issues before they become problems

- Single location for communication

- Status/error Logging (Trace back historical events)

- Notification of issues

- Everything in one place – no need to look through manuals or remember procedures for communicating with a specific device.


Example: Broken connector in Lille (September 2024)

Who done it?
...is still a mystery...

Monitoring software developed by Fibre Links

- **Network architecture:** linear network using switches and SFPs on monitoring channel on same fibre pair as dissemination.

- **Network communication:** Secure Shell (SSH)

- **User Interface:** Graphical, tabbed structure, 1 tab per device type.

- **User notification:** *-Proactive approach-* Every amplifier on the 16 remote colocations is monitored every 15 minutes, should there be a change of status an email (SMTP) is sent to selected users who can in turn investigate.
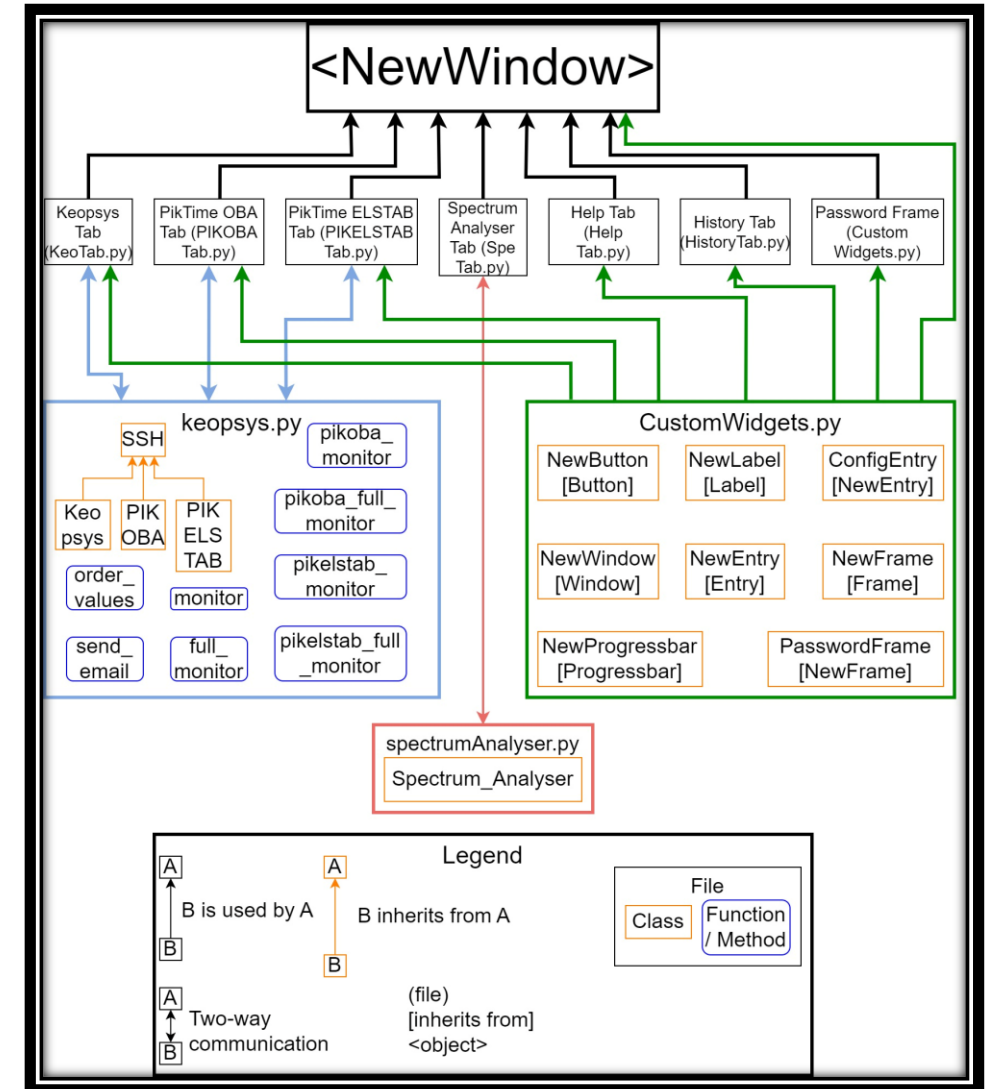
Monitoring software top level functional view

Amplifier control GUI (Whole link)

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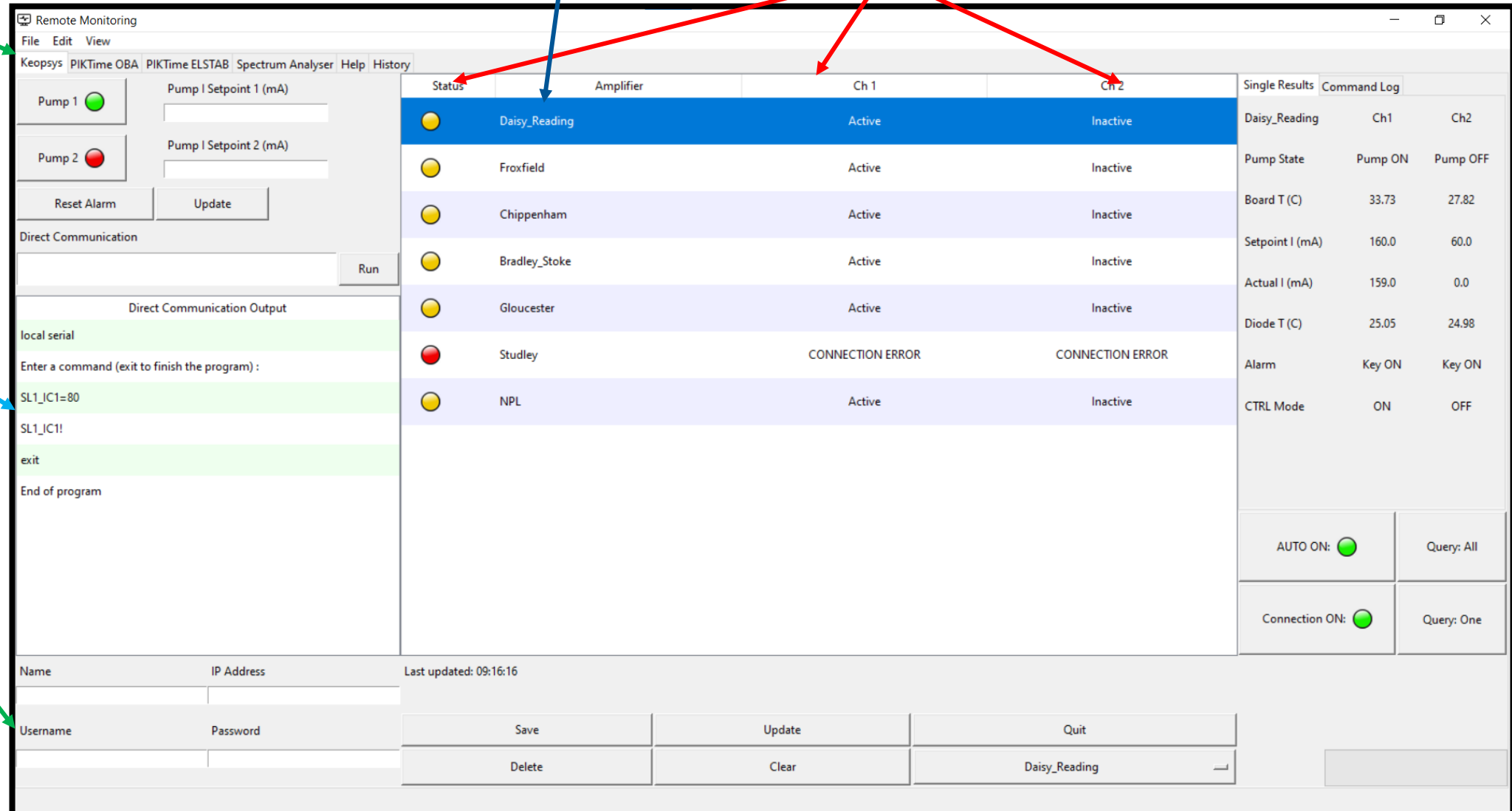
Location

EDFA Status

Tab Menu

Command line option

Configuration options

Remote Monitoring

File Edit View

Keopsys PIKTime OBA PIKTime ELSTAB Spectrum Analyser Help History

Pump 1 🟢	Pump I Setpoint 1 (mA)
Pump 2 🔴	Pump I Setpoint 2 (mA)
Reset Alarm	Update

Direct Communication

Run

Direct Communication Output

local serial

Enter a command (exit to finish the program) :

SL1_IC1=80

SL1_IC1!

exit

End of program

Status	Amplifier	Ch 1	Ch 2
🟡	Daisy_Reading	Active	Inactive
🟡	Froxfield	Active	Inactive
🟡	Chippenham	Active	Inactive
🟡	Bradley_Stoke	Active	Inactive
🟡	Gloucester	Active	Inactive
🔴	Studley	CONNECTION ERROR	CONNECTION ERROR
🟡	NPL	Active	Inactive

Single Results Command Log

	Ch1	Ch2
Daisy_Reading	Ch1	Ch2
Pump State	Pump ON	Pump OFF
Board T (C)	33.73	27.82
Setpoint I (mA)	160.0	60.0
Actual I (mA)	159.0	0.0
Diode T (C)	25.05	24.98
Alarm	Key ON	Key ON
CTRL Mode	ON	OFF

AUTO ON: 🟢   Query: All

Connection ON: 🟢   Query: One

| Name | IP Address | Last updated: 09:16:16 |
| Username | Password | |

| Save | Update | Quit |
| Delete | Clear | Daisy_Reading |

Amplifier control GUI (Whole link)

Remote monitoring and control GUI for:

- OBA-3 amps
- Keopsys amplifier
- ELSTAB modules
- Spectrum Analyser
- Scope to add instruments in future.
- Log file keeping a record of faults, uptime etc.

Note: All remotely connected devices are interrogated every **15 minutes**, and all data is saved in the server.
In case of fault an email is sent with details of location.

!!! Recent fault (broken fibre) was detected within 3 mins and fixed the same day!

Link monitoring (OFDR)

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FRM

Narrow linewidth laser

Acousto-optic modulator

Sawtooth generator
(Software Defined Radio)

$$Distance \approx \frac{freq * 2e^8}{2 * slope}$$

φ shift

Freq
Time

Freq
Ref signal
Back scattering signal
Beat frequency
Time

Above: Spectrum analyser screen, X-axis: Frequency converted to distance by calculating slope of laser modulation; Y-axis, power level in dBm.
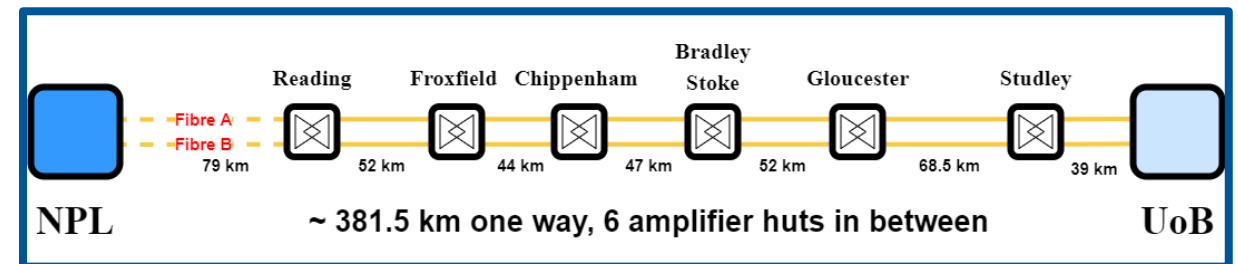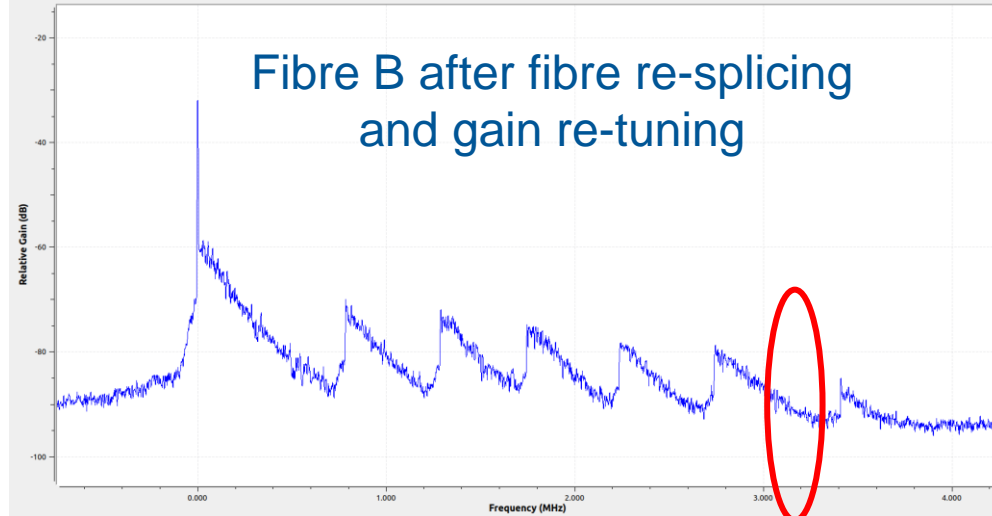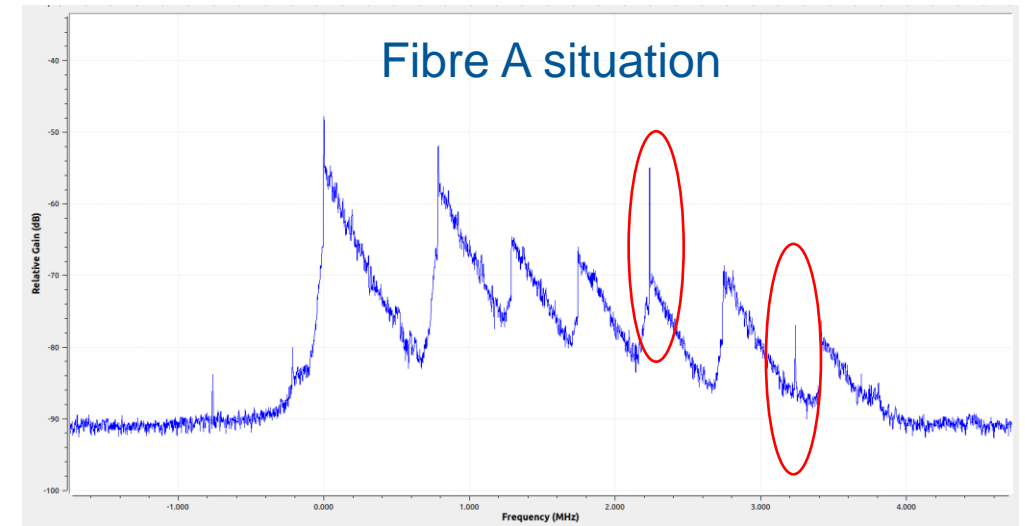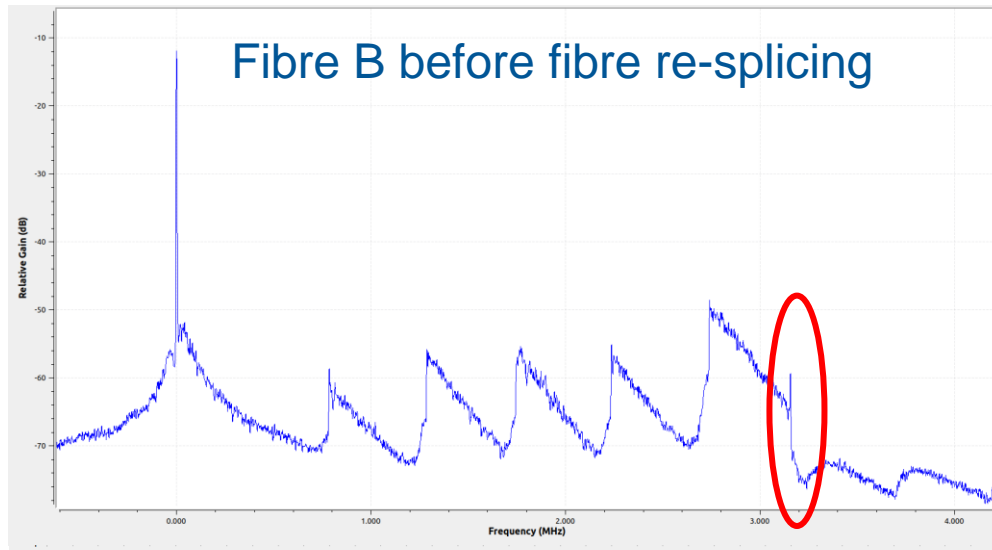
Progress on a transportable OFDR that runs in conjunction with Optical Carrier transfer. The intention is to be able to monitor the status of the link in real time therefore take a proactive approach to fault detection and classification.

Link monitoring (OFDR) 2

OFDR during a signal loss

$100 \ km \ \leftrightarrow 1 \ MHz$

Fibre B before fibre re-splicing

Fibre B after fibre re-splicing and gain re-tuning

Fibre A situation

~ 381.5 km one way, 6 amplifier huts in between

Conclusion and future work

- **Work done:** T&F signals are ready to use on NPL-Birmingham link:
  Optical Carrier (OC) > Syn**ton**isation
  ELSTAB > Synto. + Syn**chro**nisation (once calibrated > Delay, Chromatic dispersion & Sagnac effect)
  White Rabbit > Synto. + Synchro. + **Time of day**

- **Future work:**
  - Devise method for gain optimisation for both OC & ELSTAB
  - Upgrade/Test hardware for White Rabbit (Collab. With CERN/GMV)
  - Build a small form factor OFDR > How do we overcome need for narrow linewidth laser?
  - Real-time calibration on 1 PPS signals
  - L band optical carrier distribution (on Ch7), enabling use of Dark Channels
  - Use various FBGs at different band to monitor status of colocation and fibre?
  - And of course … sensing (not just seismic).