Optical Atomic Clocks for Time Dissemination in a Telecom Network

Lakshmi Rajagopal
Mike Gilson
Dr. Andrew Lord

10 November 2022

Outline

- Research work
- Optical atomic clocks
- THz to MHz frequency conversion
- Software modelling
- Optical reference system
- Conclusion

A Look into my PhD

Objective: Future telecom network Independent of satellite; Connected with optical atomic clocks for accurate time transfer

Investigate on the applications that can benefit from highly precise optical atomic clocks

MoSaiQC: ESRs looking into the modular systems for advanced integrated quantum clocks

iq-Clock: Mainly focusses on the development of physics and technology required to make new and better quantum clocks

Current Progress

PhD entirely based in BT

Enrolled with the University of Birmingham

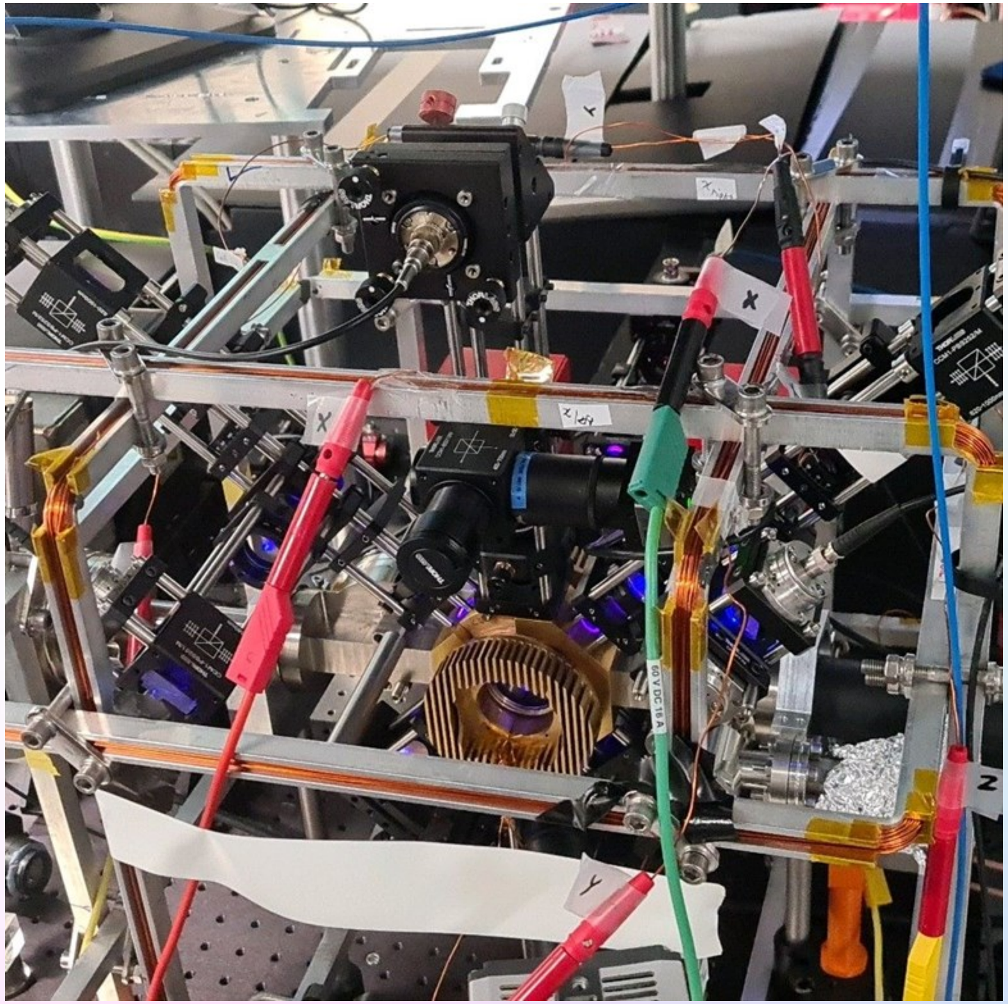
Marie-Curie fellowship based ESR

In the second year of PhD

https://www.iqclock.eu/
https://www.mosaiqc.eu/

Optical Atomic Clock

- Strontium based optical atomic clock
- Accuracy and stability to 18 significant digits
- Ultra-stable high-Q optical cavity : Transfer stability of length to stability of frequency
- Atomic sample : Transfer accuracy of energy of ultra-precise atomic clock transition to frequency accuracy
- Frequency compared with frequency shifter & feedback added to laser frequency



Initial prototype of Sr based optical atomic clock at UoB

https://www.linkedin.com/feed/update/urn:li:activity:6869972116033290240/

Why Optical Atomic Clocks?

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TEST & MEASUREMENT > TEST & MEASUREMENT

Optical atomic clocks move closer to replacing microwave atomic clocks

This new generation of optical atomic clocks is accurate and robust enough to redefine the official length of a second.

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SCIENCE & RESEARCH

Portable optical clocks stay 'on,' thanks to a microcomb trick

By inserting the microcavity inside a laser, scientists generate soliton pulses to keep portable optical clocks in an 'on' state.

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APRIL 27, 2012

Atomic clock comparison via data highways

by Max Planck Society

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Artist's view of the experiment. Graphic: MPQ (WoogieWorks, Vienna)

(Phys.org) -- Optical atomic clocks measure time with unprecedented accuracy. However, it is the ability to compare clocks with one another that makes them applicable for high-precision tests in fundamental theory, from cosmology all the way to quantum physics. A clock comparison, i.e. a comparison of their optical frequencies, proved to be challenging so far as the few existing optical clocks around the world are not readily portable due to their complex nature.

A team of researchers from the Physikalisch-TechnischeBundesanstalt (PTB) in Braunschweig and from the Laser Spectroscopy Division at the Max Planck Institute of Quantum Optics (MPQ) in Garching have now demonstrated an optical frequency transfer with high stability through a standard telecommunication optical fiber network (*Science*, April 27, 2012).

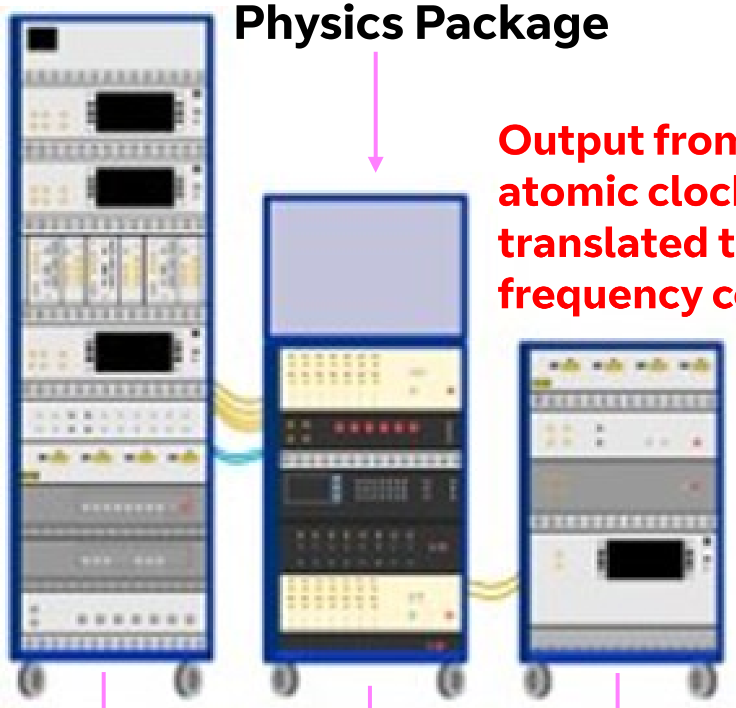
The optical fiber connecting the two institutes was installed below ground and had a total length of 920 kilometers. This demonstration enables the ability to compare optical clocks located far apart from each other and to transmit their stability to distant laboratories where the signals can be used for high precision experiments. At first, fundamental research will benefit from this, e.g. in the precise determination of natural constants, tests of the validity of Einstein's theory of General Relativity or for predictions in quantum electrodynamics.

In an atomic clock the frequency that an atom emits when changing from one energy level to another defines the unit of time. The unit "second" is the interval occupied by 9,192,631,770 cycles of the microwave radiation corresponding to a transition of the cesium-133 isotope. The generation and dissemination of the second is statutory and in Germany the duty of the PTB. Optical atomic clocks use a frequency that is about 100,000 times higher compared to microwave clocks and thus slice time into much finer intervals. The latest generation of optical atomic clocks differs only in the 18th decimal place – that corresponds to one second in a time period of the age of the universe.

Physicists 'switch on' the future for ultra-precise optical clocks | University of Strathclyde
Portable optical clocks stay 'on,' thanks to a microcomb trick | Laser Focus World
Atomic clock comparison via data highways (phys.org)

THz to 10MHz/ 1PPS Signal

Physics Package



Laser systems & Frequency comb

Control unit

Optical cavity

Output from an optical atomic clock is THz which is translated to MHz with a frequency comb

Downconverter

10MHz

1PPS

Downconverter converts MHz signal to 10MHz/ 1PPS output

Accept 10MHz/ 1PPS input & TOD information can be taken from the timing rack

Equipment

Transportable optical atomic clocks for use in out-of-the-lab environments (degruyter.com)

Software Modelling (1/2)

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Source	Dest	Type	Length	Hops	Bandwidtl	Nodes							
Q2	F2	Primary	486.24	7	175.63	Q2	O3	O2	I3	B4	L	W1	F2

Input used for computation

- Model a timing architecture comprising of clocks, core and tier nodes
- Understand how time, phase and frequency is transferred across a network
- Evaluate the effect of asymmetries (on node and transmission link) on time transfer
- Cost vs accuracy

Details

Programming Language: C#

Calculate the time error based on given source and destination node

Static time errors and asymmetries taken into consideration

Next step: Optimization and best routing path selection based on TE

Software Modelling (2/2)

Optical Atomic Clocks

No. of optical atomic clocks required to disseminate time at National level – x (being investigated)

Approximate Cost

Assumption: Network is upgraded to latest technology

Additional cost = (x * Cost of Optical atomic clocks) * (y * Cost of link setup)

y1 (Links interconnecting the clocks) + y2 (Links from optical atomic clocks connecting the required nodes)

Error Handling

The optical atomic clocks are interconnected with each other to act as a backup in case of failure. The core is connected to multiple sources to sustain stability in case one fails

```
File directory and name used for computation
--------------------------------

Current Directory : C:\Lakshmi\Modelling\Diversity\Ver7\TimeError\bin\Debug\netcoreapp3.1
File name with location : C:\Lakshmi\Modelling\Diversity\Ver7\TimeError\bin\Debug\netcoreapp3.1\iptraffic.csv

Display the data used for calculation
-------------------------
```

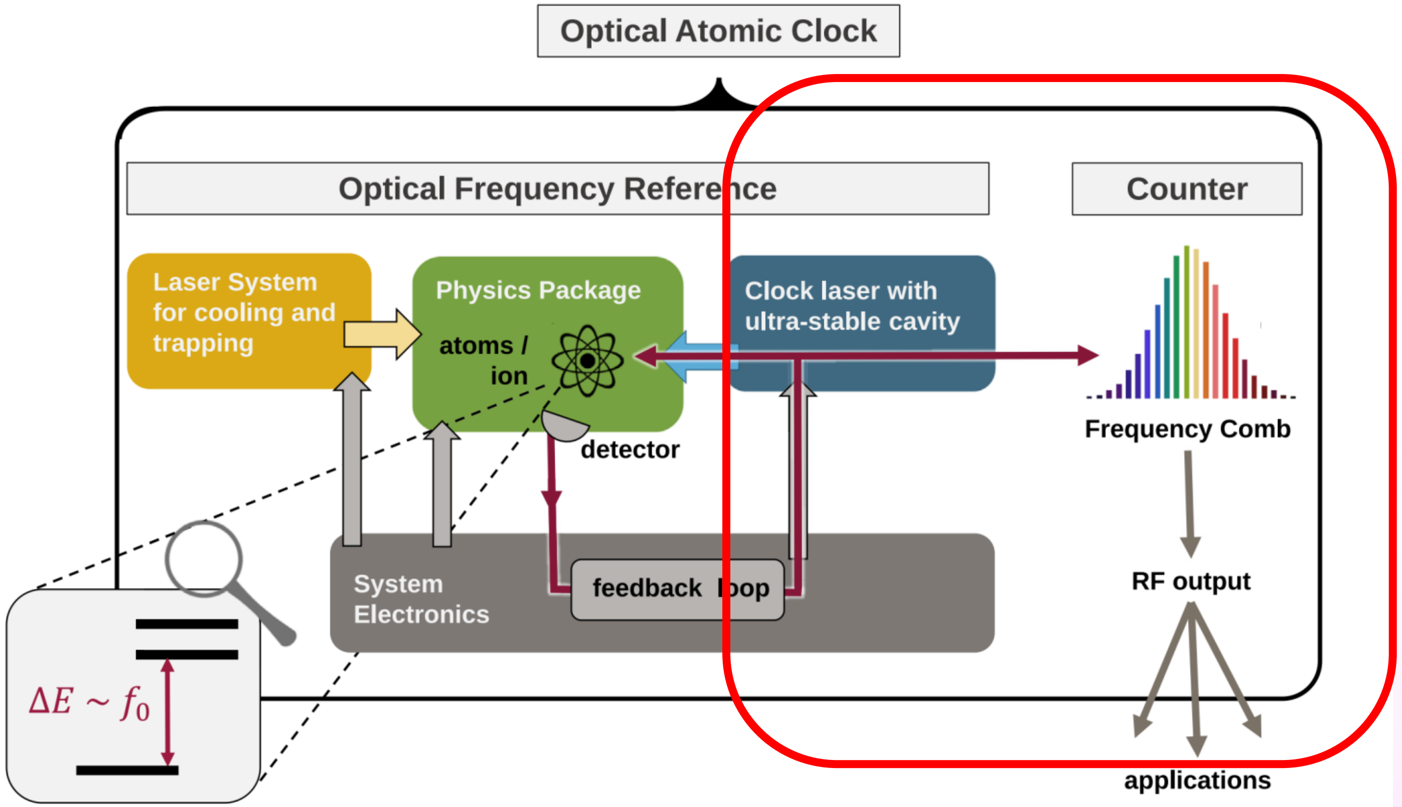
Link Characteristics	Values
Source Node	Q2
Destination Node	F2
Routing Model	Secondary
Refrective Index	1.4
Delay in transmitter component	3.1507E-05
Delay in receiver component	3.1507E-05
Length (in km)	527.92
Number of nodes	10

Link Characteristics

Src Node	Dest Node	No. of Links	No. of CL - CL Links	No. of CL - CO Links	No. of CL - TI Links	No. of CO - CO Links	No. of CO - TI Links	No. of TI - TI Links	Calculated Time Error
Q2	F2	7	0	0	0	0	2	5	5.39E-08
Q2	F2	10	0	0	0	0	4	6	6.06E-08
F2	Q2	7	0	0	0	0	2	5	5.39E-08
F2	Q2	10	0	0	0	0	4	6	6.06E-08
F2	R	5	0	0	0	0	4	1	4.63E-08
F2	R	6	0	0	0	0	2	4	4.93E-08
R	F2	5	0	0	0	0	4	1	4.63E-08
R	F2	6	0	0	0	0	2	4	4.93E-08
F2	O1	11	0	0	0	0	4	7	7.31E-08
F2	O1	14	0	0	0	0	4	10	7.76E-08
O1	F2	11	0	0	0	0	4	7	7.31E-08
O1	F2	14	0	0	0	0	4	10	7.76E-08
U2	F2	3	0	0	0	0	2	1	3.89E-08
U2	F2	4	0	0	0	0	2	2	4.14E-08
F2	U2	3	0	0	0	0	2	1	3.89E-08
F2	U2	4	0	0	0	0	2	2	4.14E-08
V2	D	3	0	0	0	0	0	3	3.87E-08
V2	D	3	0	0	0	0	0	3	3.92E-08
D	V2	3	0	0	0	0	0	3	3.87E-08
D	V2	3	0	0	0	0	0	3	3.92E-08
V2	Y1	8	0	0	0	0	1	7	5.56E-08

TE Calculations

Optical Reference System (1/6)



Optical Reference System comprising of the laser cavity and frequency comb

10MHz

[Transportable optical atomic clocks for use in out-of-the-lab environments (degruyter.com)]

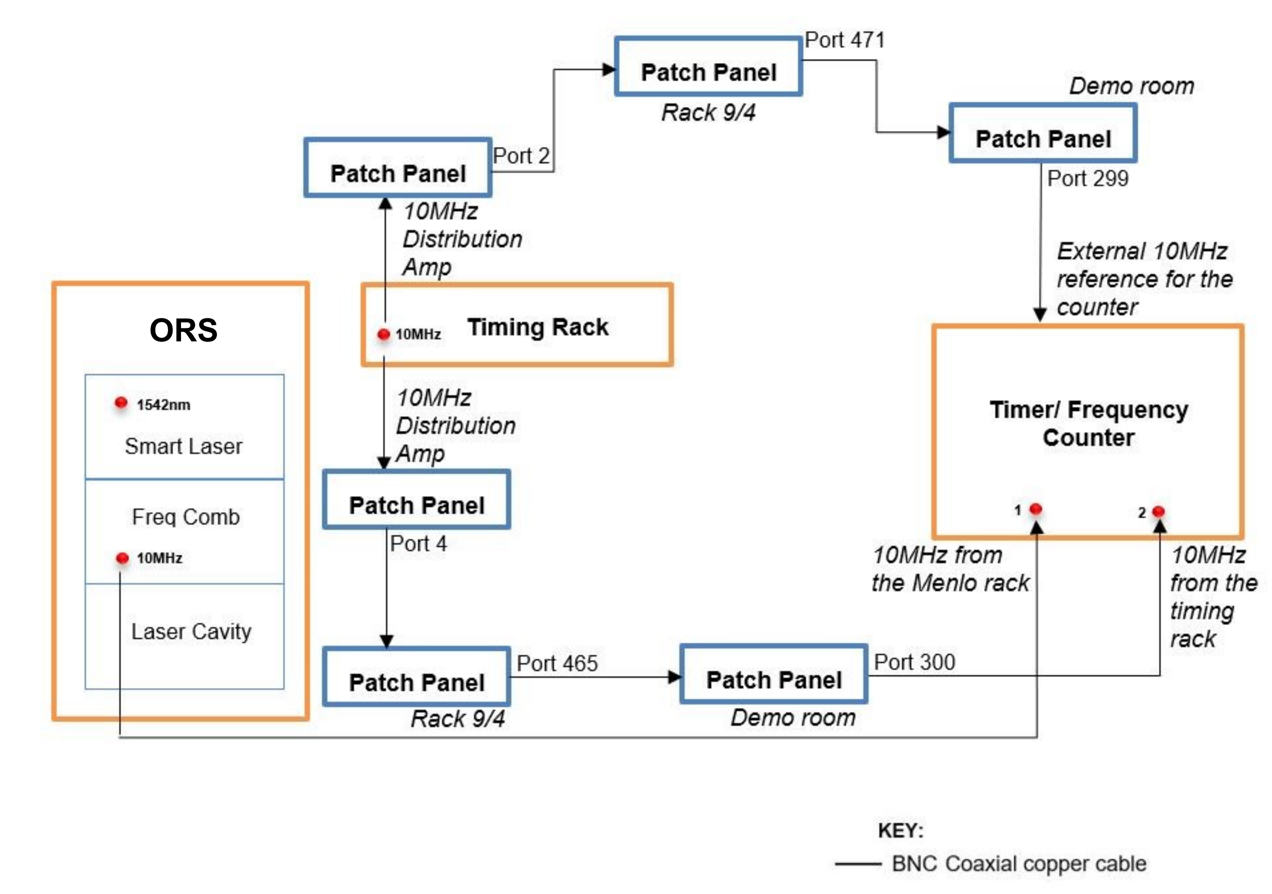
Optical Reference System (2/6)

Aim: Evaluate the long-term stability and accuracy of the device in generating a stable 10MHz output over time

Compared against a stable frequency source in the lab.

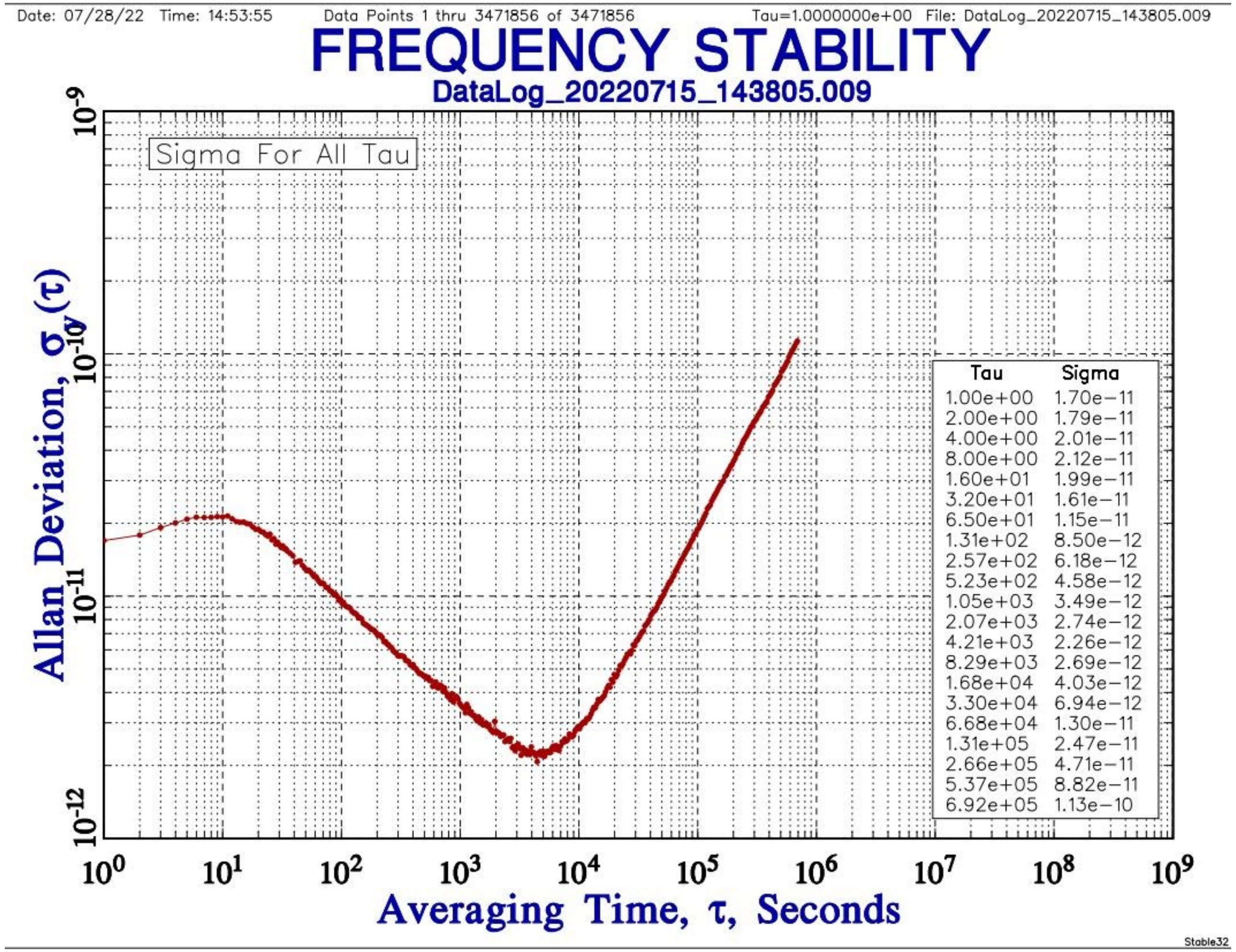
Frequency measurements were recorded to plot the Allan Deviation graph to understand the long-term stability from the device.

The experiment was run for a period of 42 days.



Experimental setup for understanding long term stability

Optical Reference System (3/6)



Allan Deviation plot indicating stability

- ✓ The device took time to calibrate to attain initial stability
- ✓ Stability improved over the later period
- ✓ Gradually started to drift over the longer term

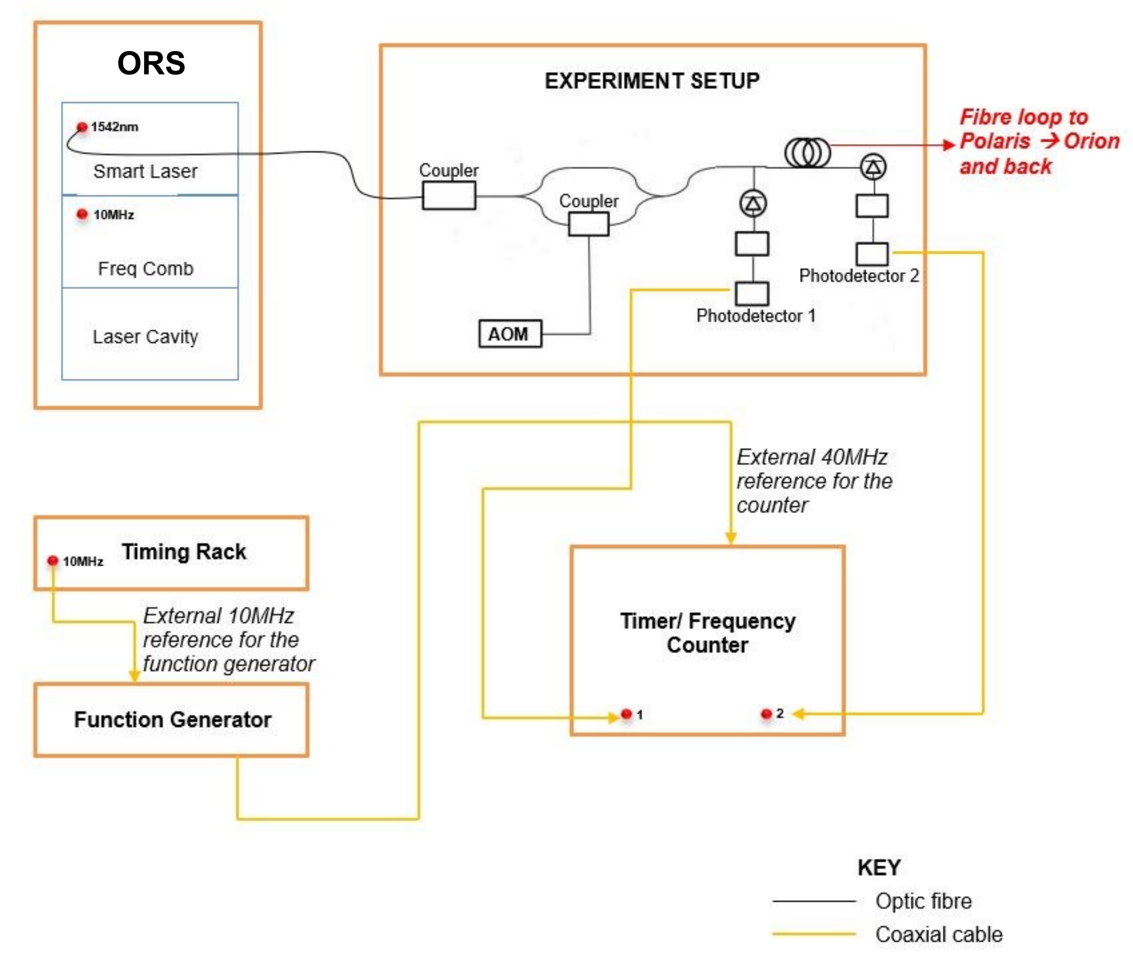
Optical Reference System (4/6)

Aim: To understand a novel method of disseminating frequency by sending a modulated laser signal across fiber

Signal at the transmitter and receiver ends were compared to understand the drift in frequency.

Frequency measurements were recorded to plot the Allan Deviation graph to understand the drift in frequency over longer period.

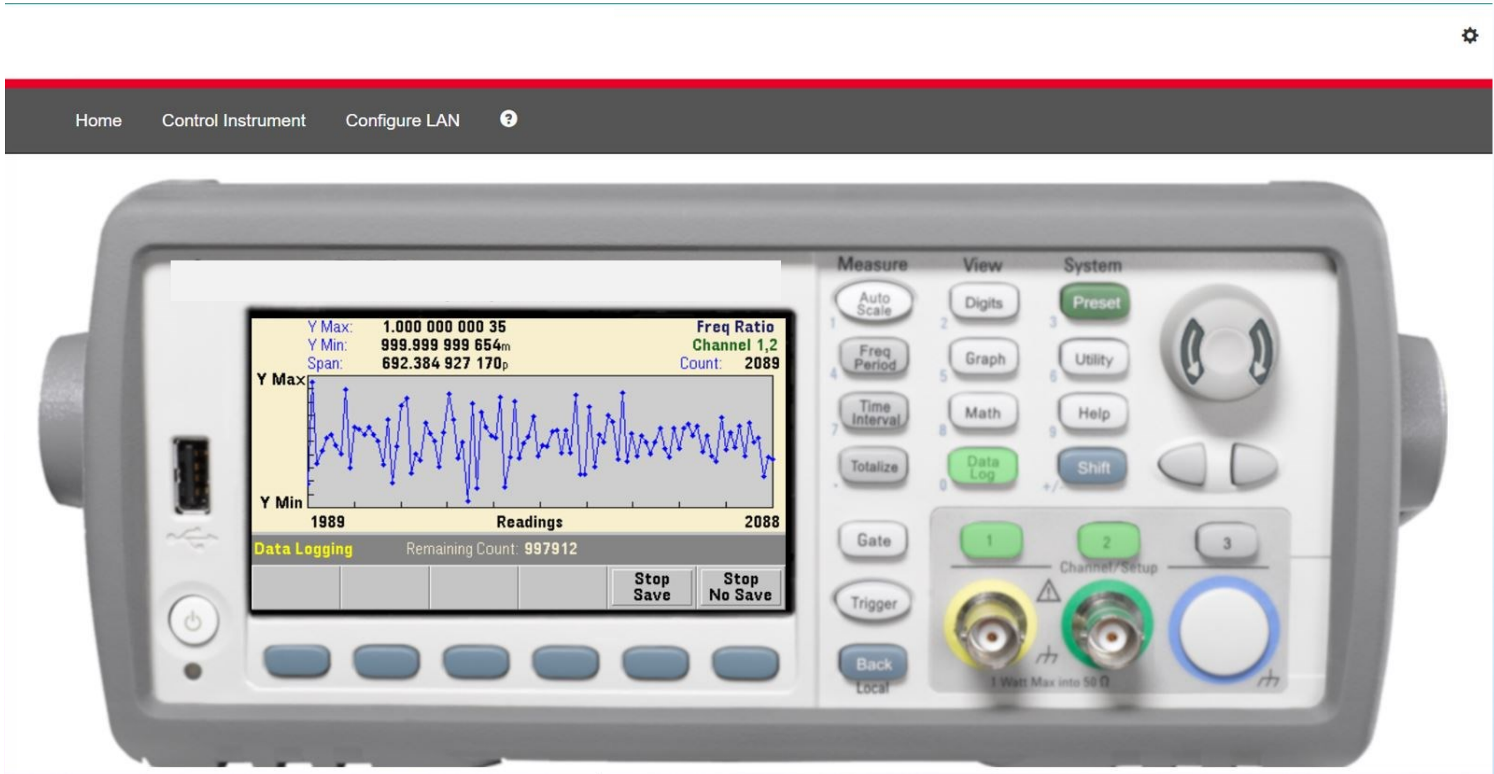
The experiment was done on fiber spool in lab and test link running few kilometres, both with approximately similar length.



Experimental setup for frequency transfer

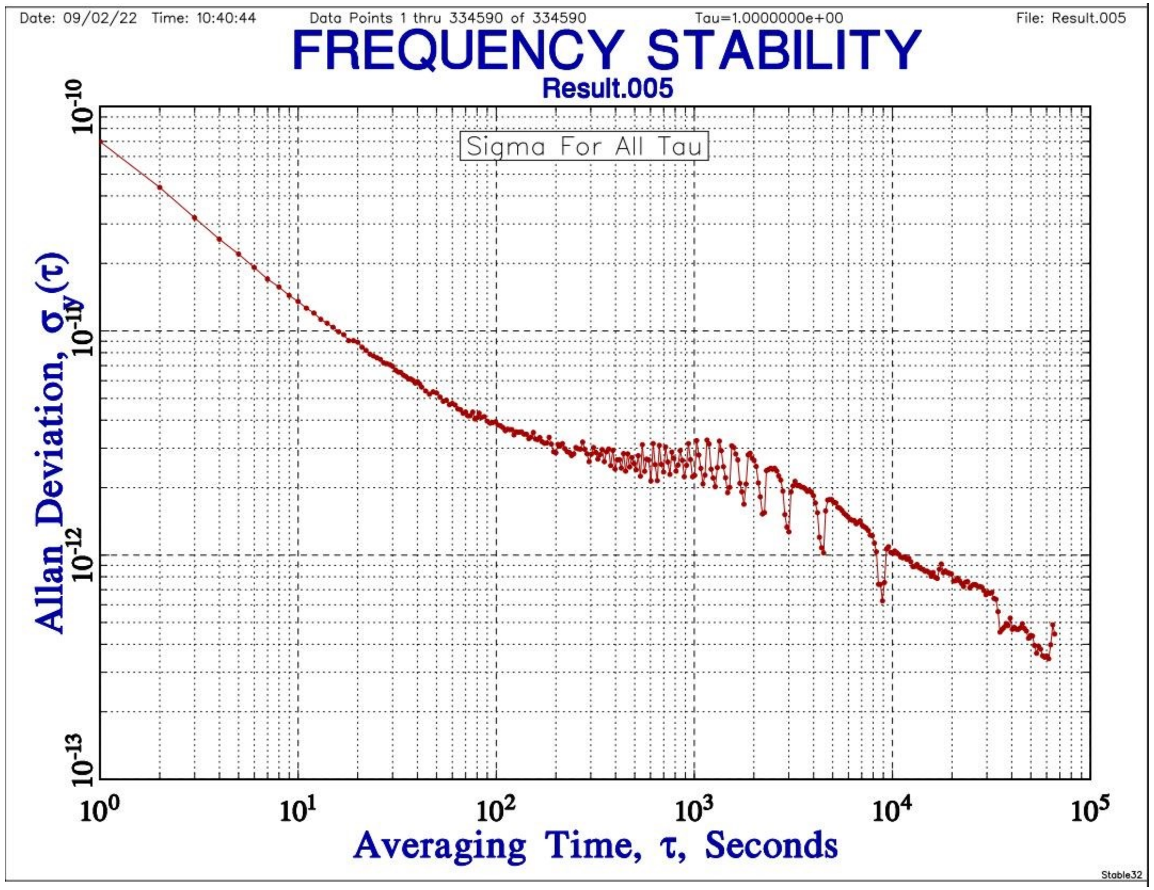
Optical Reference System (5/6)

- The fiber picked up small disturbances, which resulted in frequency deviation
- The high peaks in the screen shot correspond to the higher levels of frequency drifts produced, as a result of disturbances added into the fiber
- The shorter peaks in the screen shot correspond to the lower levels of frequency drifts produced, as the fiber was kept quite stable
- Contribute to a novel interferometry technique using optical atomic clocks in future

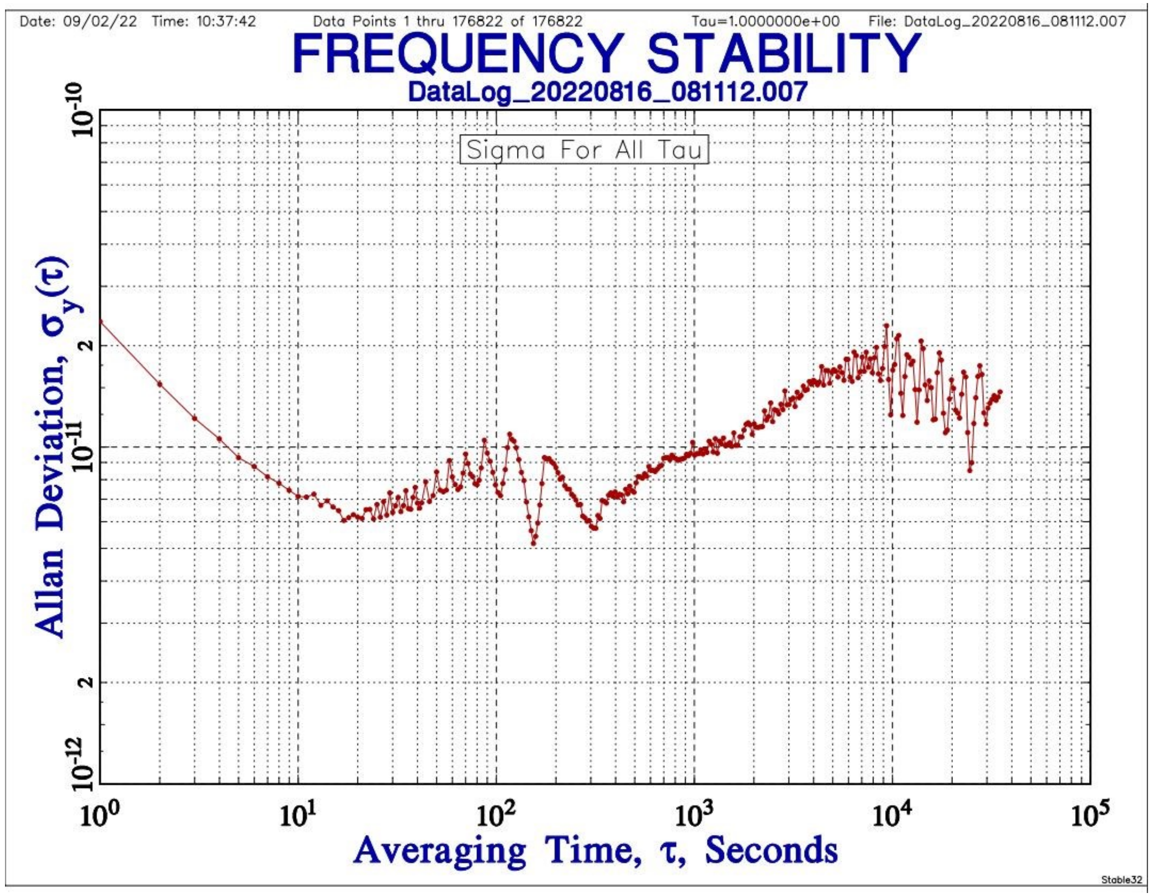


Frequency drift observed in the timer/ frequency counter

Optical Reference System (6/6)



Allan Deviation graph for 4.8km fiber test link



Allan Deviation graph for 4km fiber spool

Conclusion and Future Scopes

- Level of resilience from the technology
- Compensate for the asymmetry
- What can be the backup technology in case of failure?
- Size of the clock
- Consumption of power and cost per node to distribute time, frequency and phase
- Coverage from the technology
- Optical clocks for sensing applications