Optical frequency carrier transfer for sensory networks

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CLONETS Training Event at NPL 26th Feb 2019

The origin of motivation for optical carrier transfer

Temelin Nuclear Power Station, Czech Republic

- owned by CEZ Group Czech Republic
- two reactors, each protected by the **containment building**
- 2,000 MW of total installed electrical capacity - largest power resource in CR

Owner of NPP is responsible for safety and long-term measurement of the stability and shape deviation of the containment building.

Need for precise monitoring of strain in the containment building walls due **aging of linking cables in channels and used concrete**.

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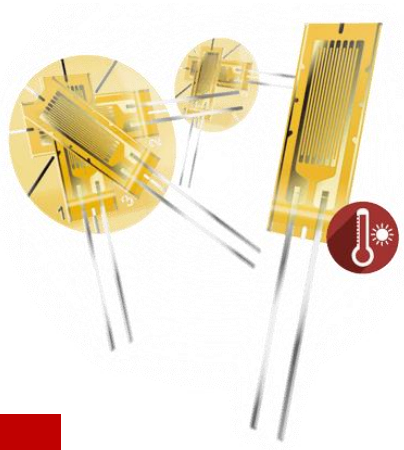
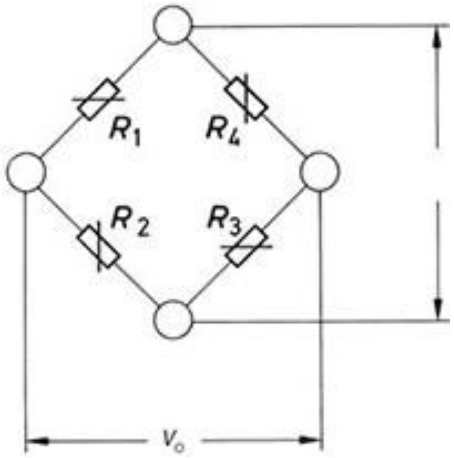
Which kind of sensors to use?

Electrical strain gauges

- based on the electrical resistance change with strain change
- very sensitive, relatively low-cost, variety of forms
- concreting in containments of NPP Temelin in 1987 - 1995
- but increasing failures after 2010
- thus – monitoring of the containment is not sufficient





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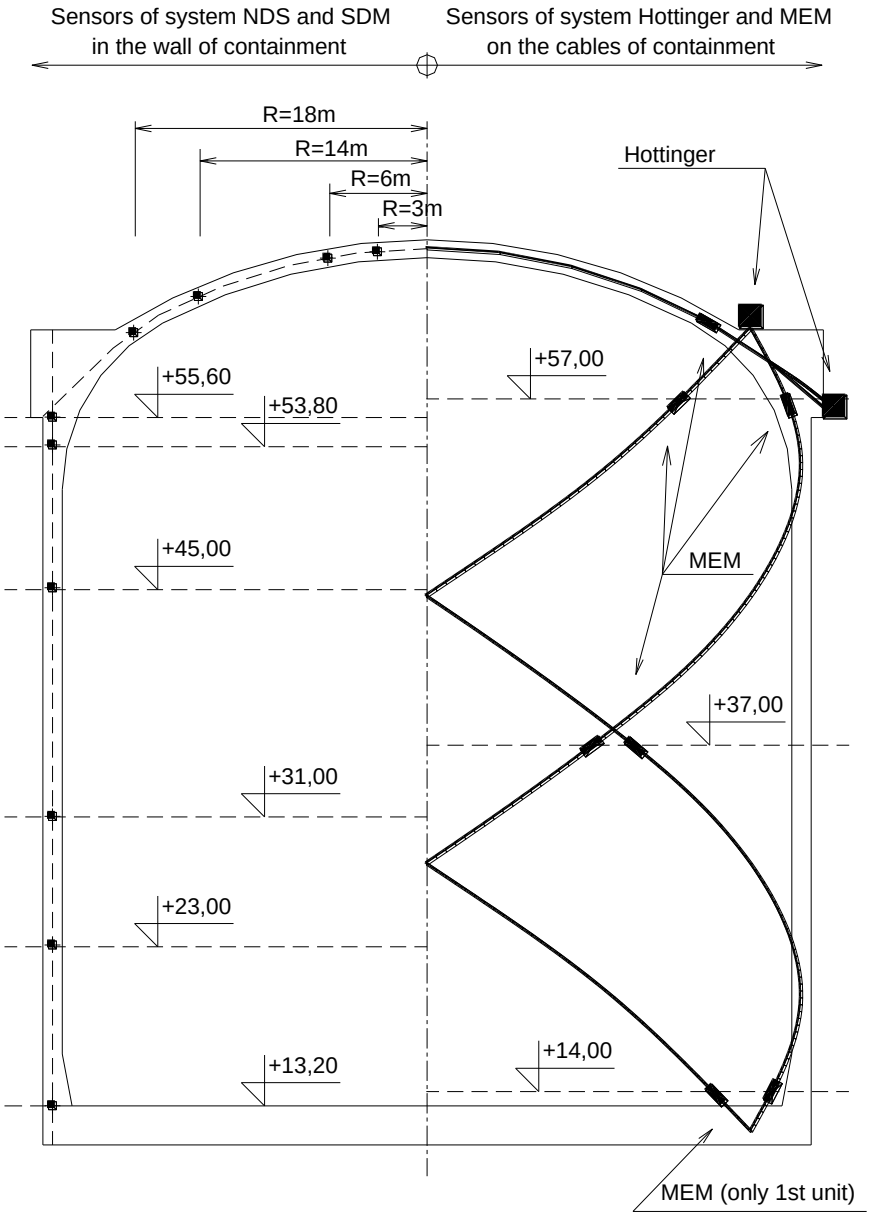
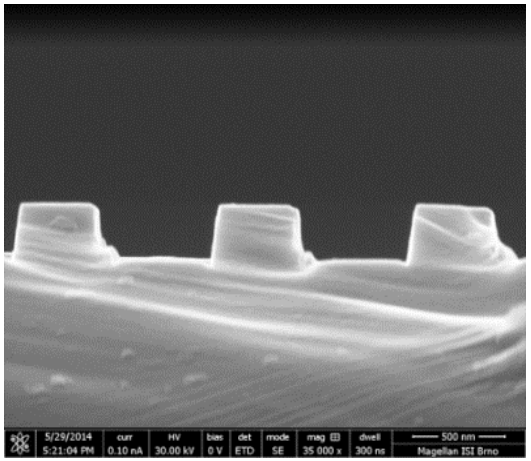
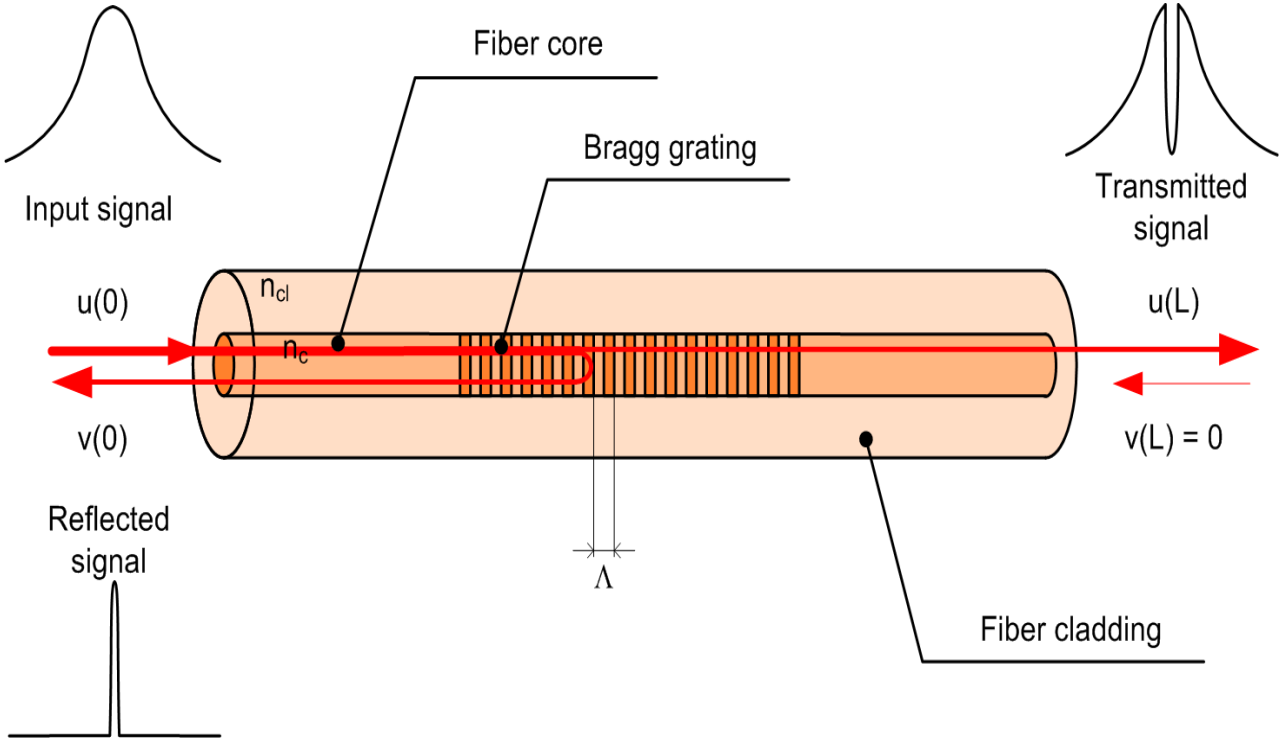


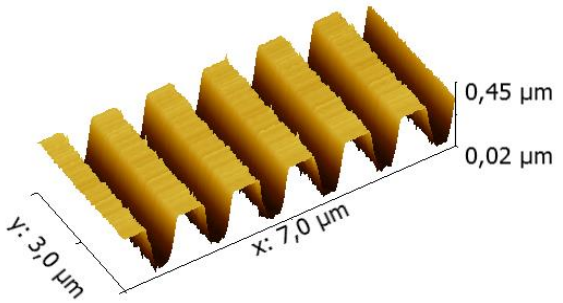
Towards all-photonic sensors

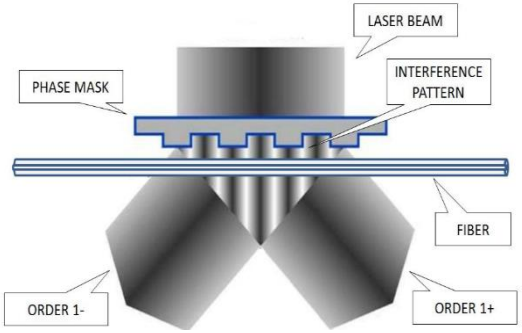
Fibre Bragg Grating gauges (FBG)

- works on the principle of filtering the input optical spectrum
- band-pass filter configuration is very useful for strain detection
- length (strain) of the FBS sets the reflecting central wavelength
- very sensitive, interrogation by a high-resolution spectrometer
- advantage – all-photonics, no EMC issues

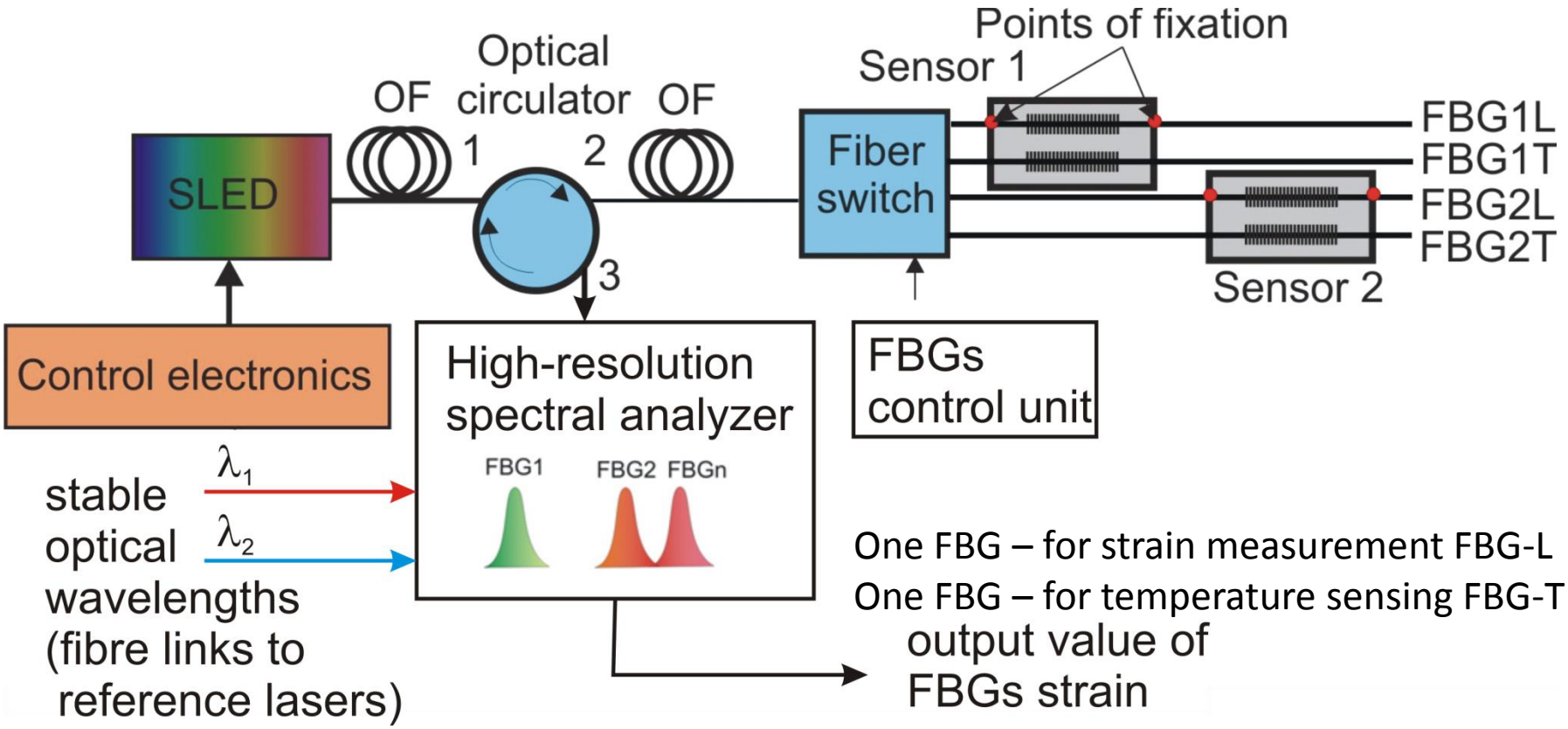








Principle of strain detection by FBG sensors

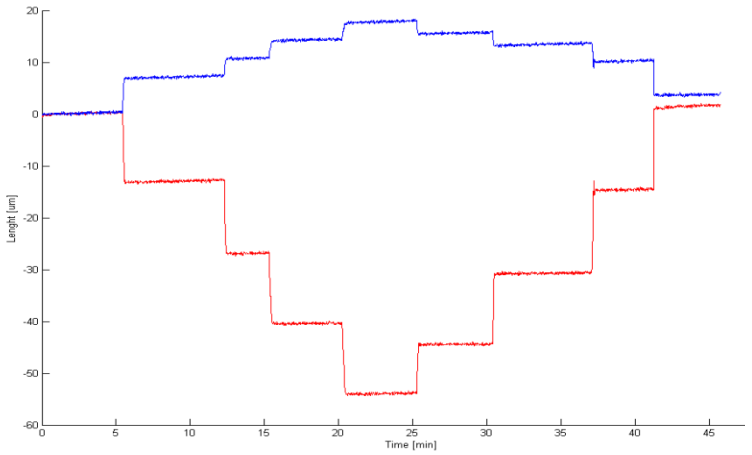


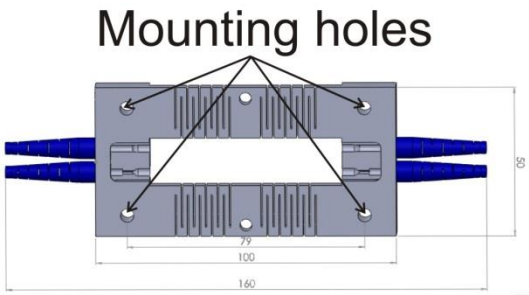
High-resolution spectral analyzer interrogates band-pass optical frequencies (wavelengths) of particular FBG strain sensors in the sensory network.

The stability of absolute measurement is determined mainly by an optical frequency standard referencing the spectral analyzer.

FBG strain gauge sensor test bed

The first implementation of FBG strain gauges on concrete block demonstrator (lab of **Institute of Nuclear Research – UJV Řež**)





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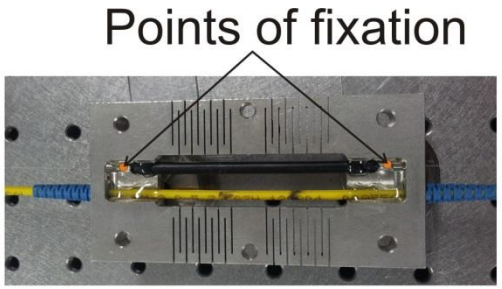


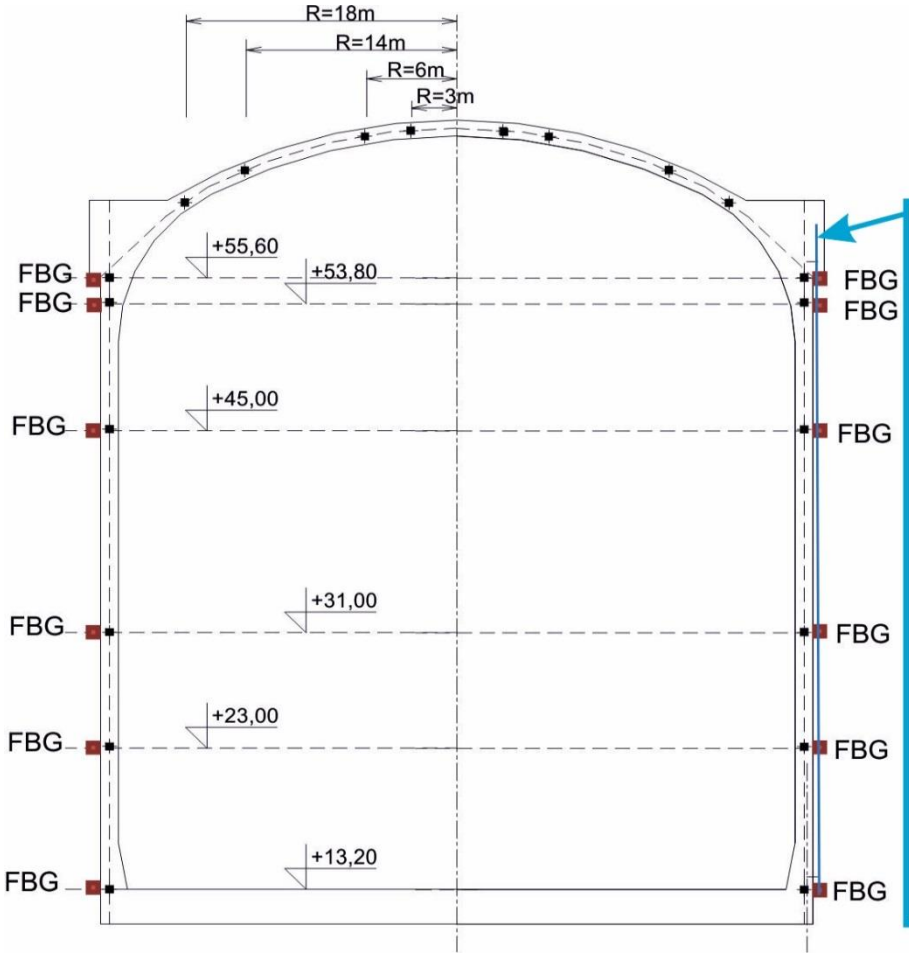
b)

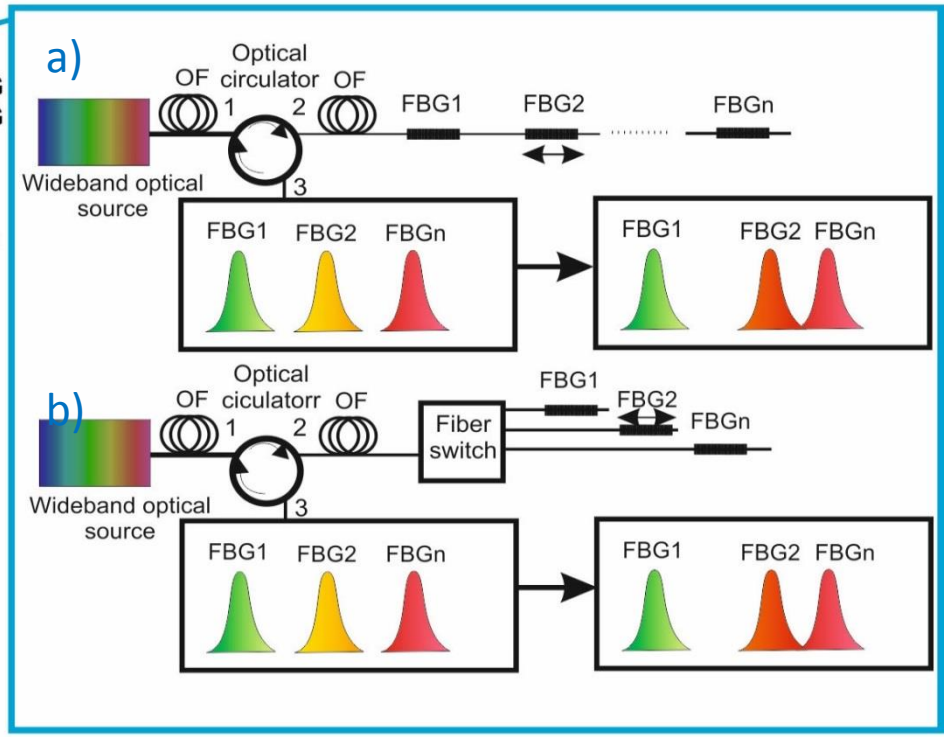
Design of FBG strain sensory network for NPP Temelin

Two possibilities of FBG strain networks can be assembled:

a) **Serial** combination of FBG sensors / **parallel** reading of data

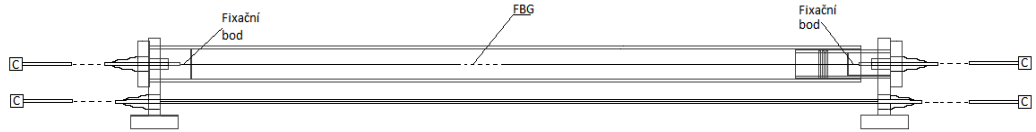
b) **Parallel** combination of FBG sensors / **serial** reading of data

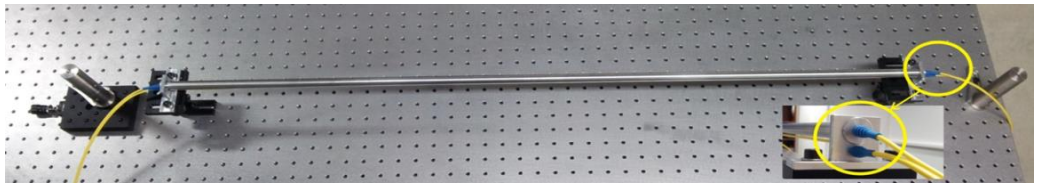


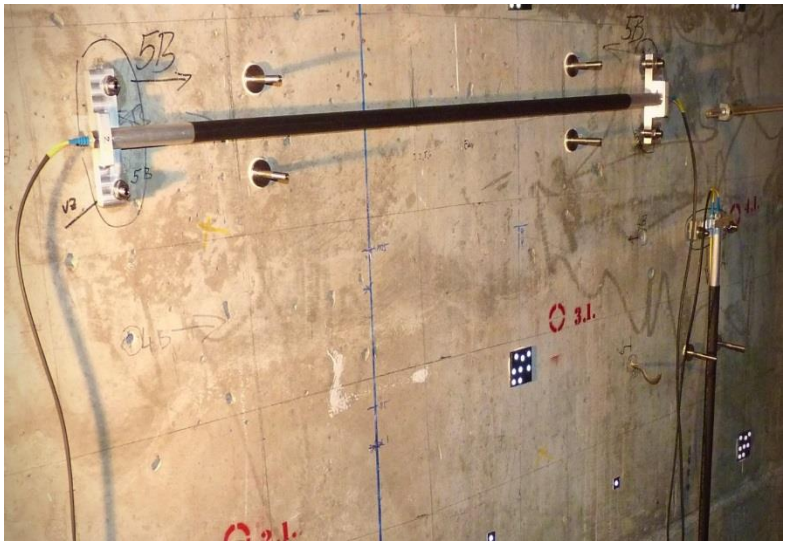


Pilot implementation of FBG sensors in NPP Temelin

May 2015: Two combined FBG strain/temperature sensors installed in NPP Temelin – reactor 2







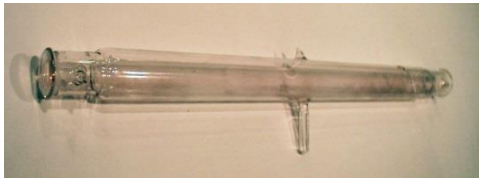
ISI CAS Institute of Scientific Instruments The Czech Academy of Sciences

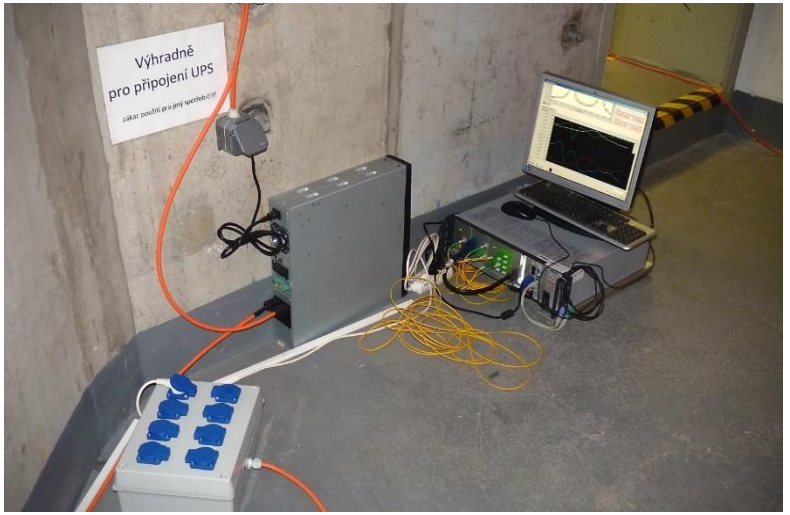
ÚJV

NETWORK group

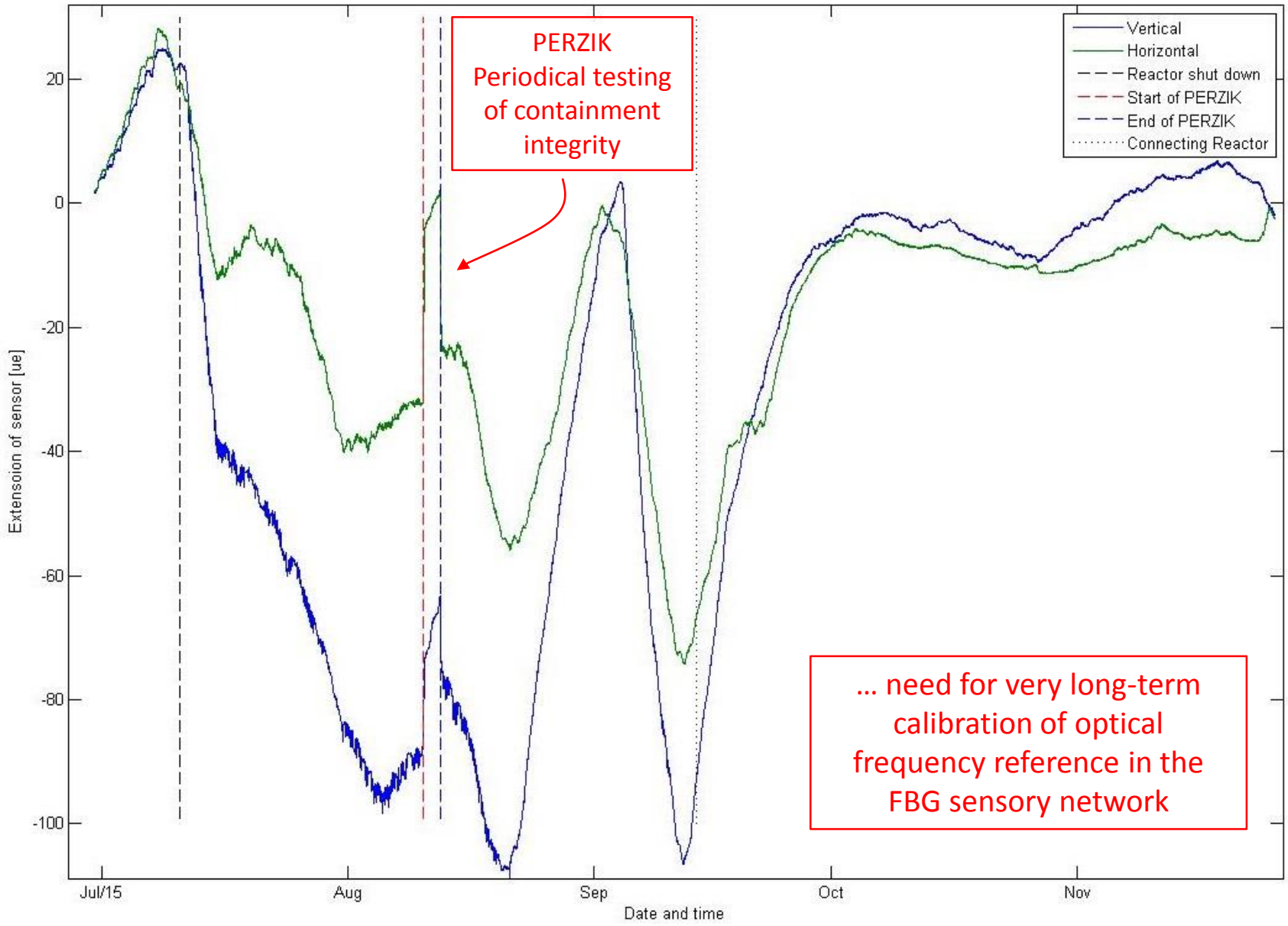
Optical frequency reference: **C2H2linear absorption**

Interrogator: **scanning Fabry-Perot interferometer**



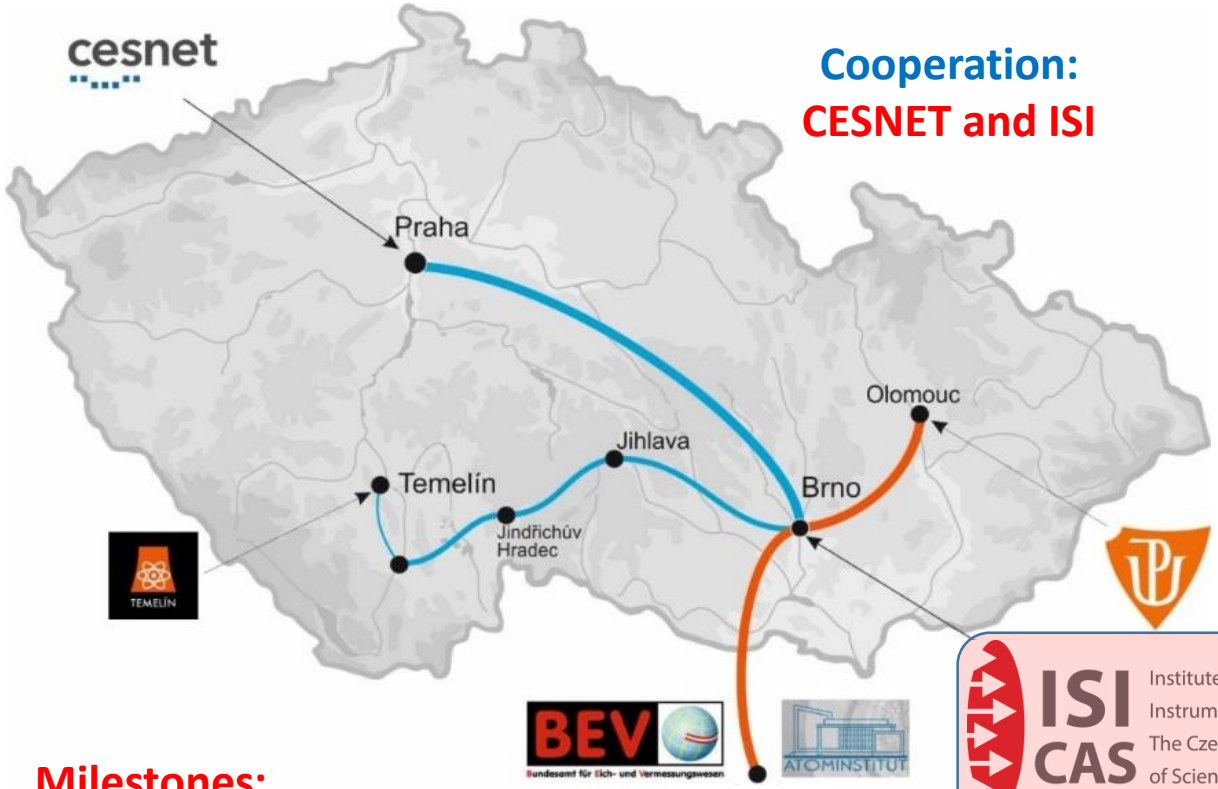


Pilot implementation of FBG sensors in NPP Temelin



Optical carrier coherent transfer in Central Europe

Main idea: … to broadcast ultra-stable optical carrier at telecom bands to destination where optical frequency calibration at absolute stability < 10^{-13} is needed …



Cooperation:
CESNET and ISI

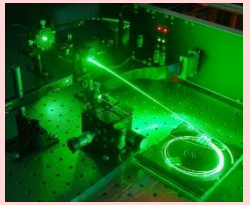
ISI CAS Institute of Scientific Instruments The Czech Academy of Sciences

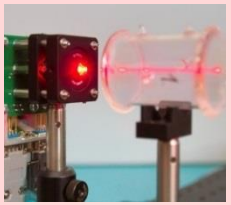
Milestones:

2015: ISI – CESNET Prague 306km
2018: ISI – NPP Temelin 401km
2019: ISI – BEV Vienna 280km
2020: ISI – UP Olomouc 120km

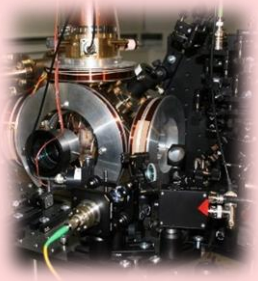
Issue: induced Doppler shift in optical fibres (fibre phase noise) limits stability of transferred reference

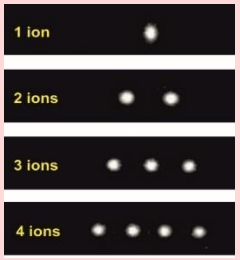
Optical frequency standards





$^{40}Ca^{+}$ ion clocks @ 729 nm





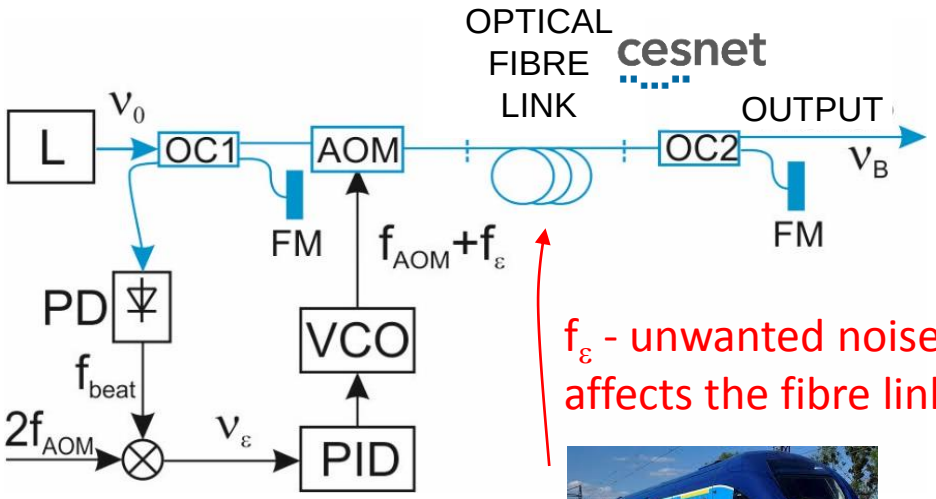
Supercoherent lasers 1540/729 nm

Optical frequency combs

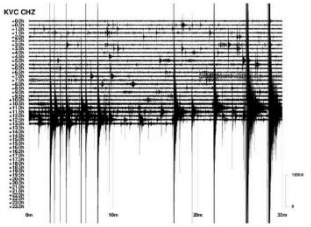
Optical carrier coherent transfer - principle

The transmission link always has a traffic delay, which for stable signals, such as atomic clock optical frequency, can usually degrade the stability of these clocks due induced phase noise into the traffic delay.

SOLUTION: bidirectional transmission of information at the same time (interferometer)



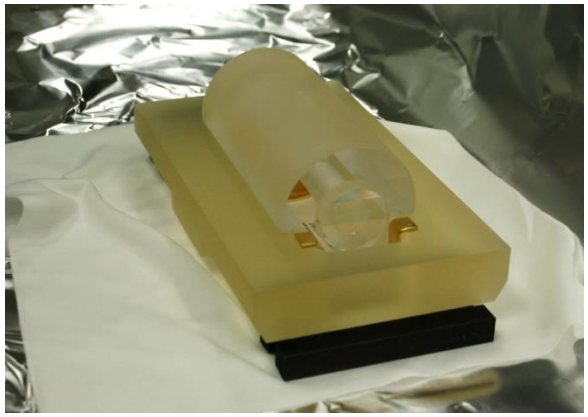
f_ε - unwanted noise signal
affects the fibre link transport delay

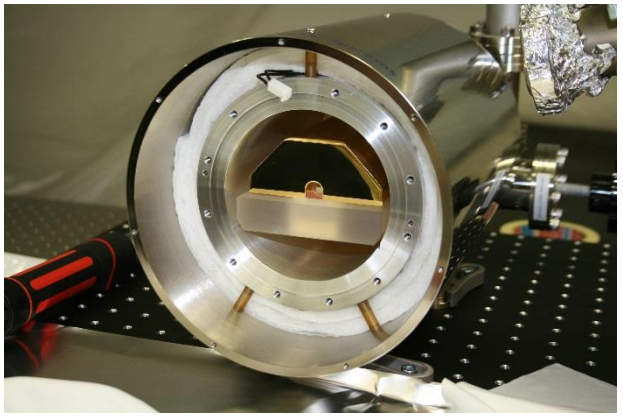


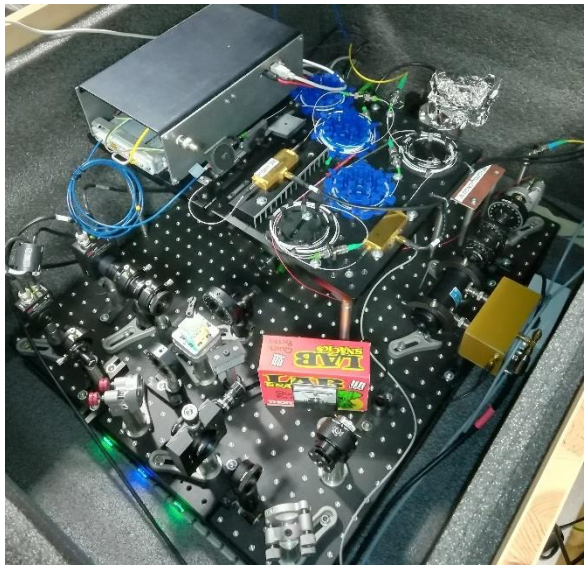
More theory - Jochen & Amy lectures

Laser C1540 at 1540 nm for optical carrier coherent transfer

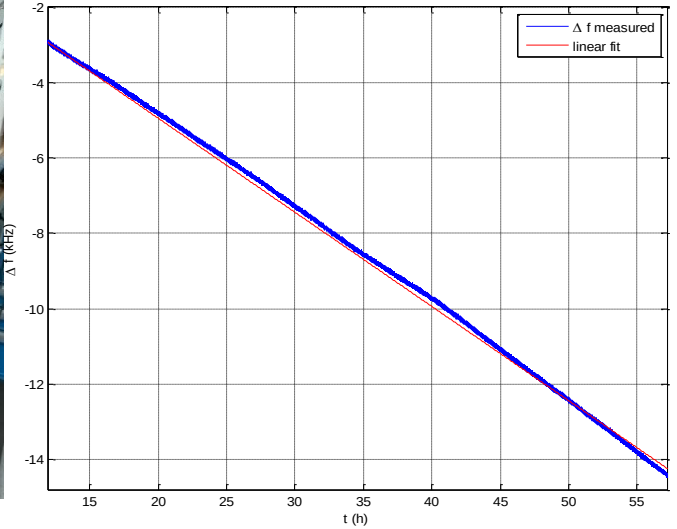
Supercoherent laser at 1540 nm was completed. In combination with optical frequency comb and H-maser this is the optical reference used for distribution future ISI optical clock using fibre links.



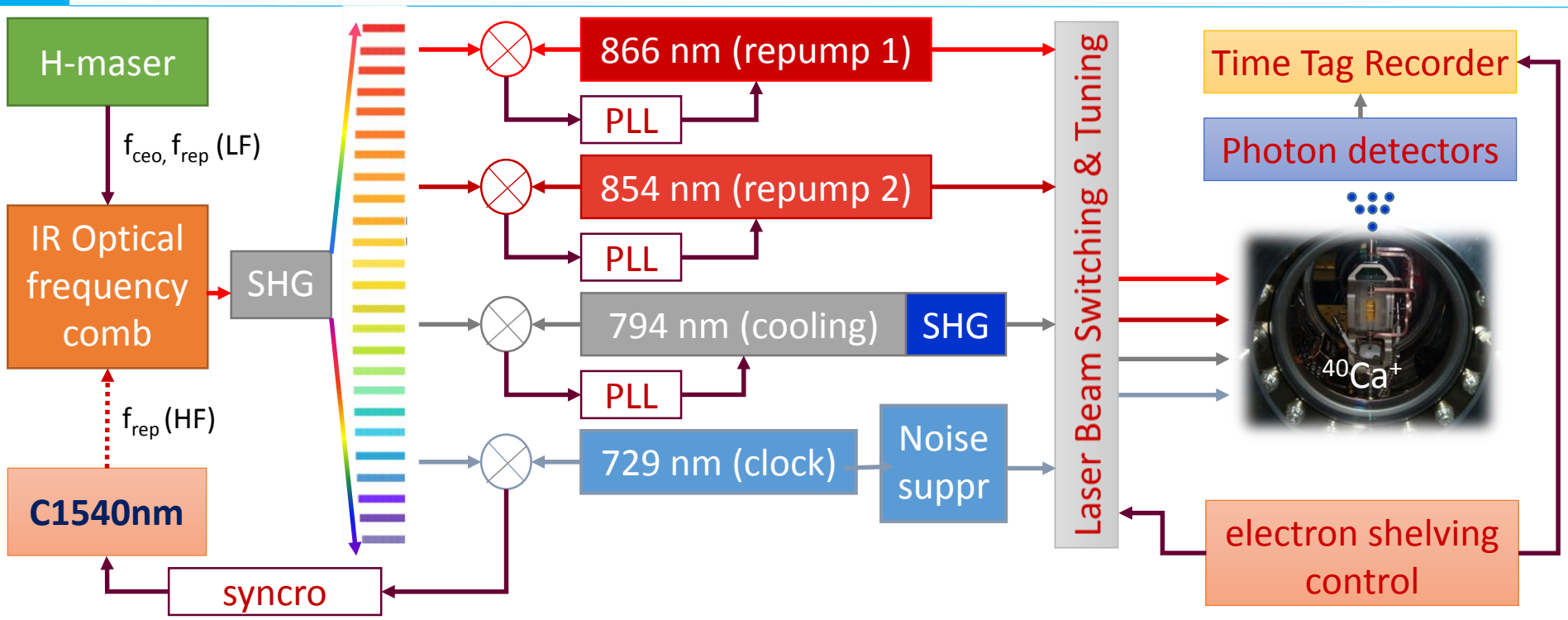


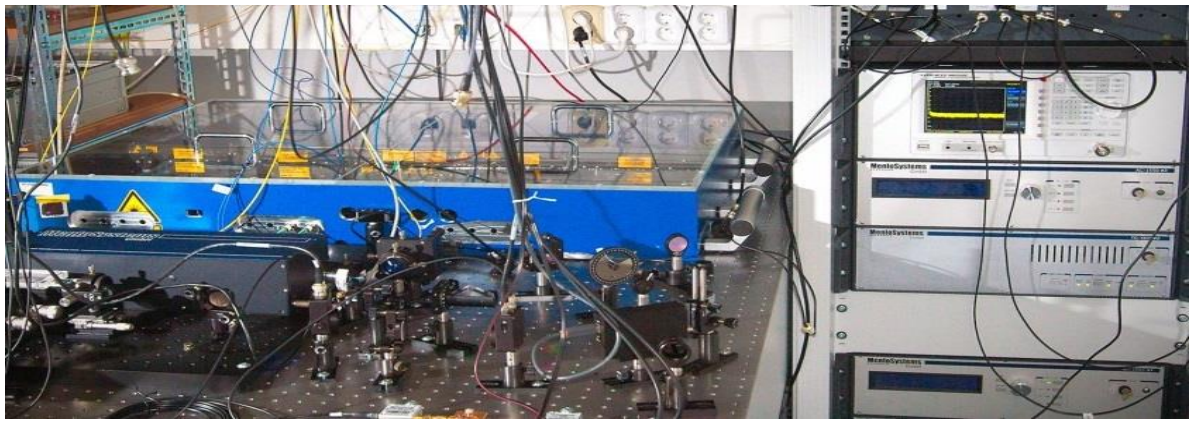


Long-term aging of cavity: -0,07 Hz.s^{-1}



ISI optical frequency scale



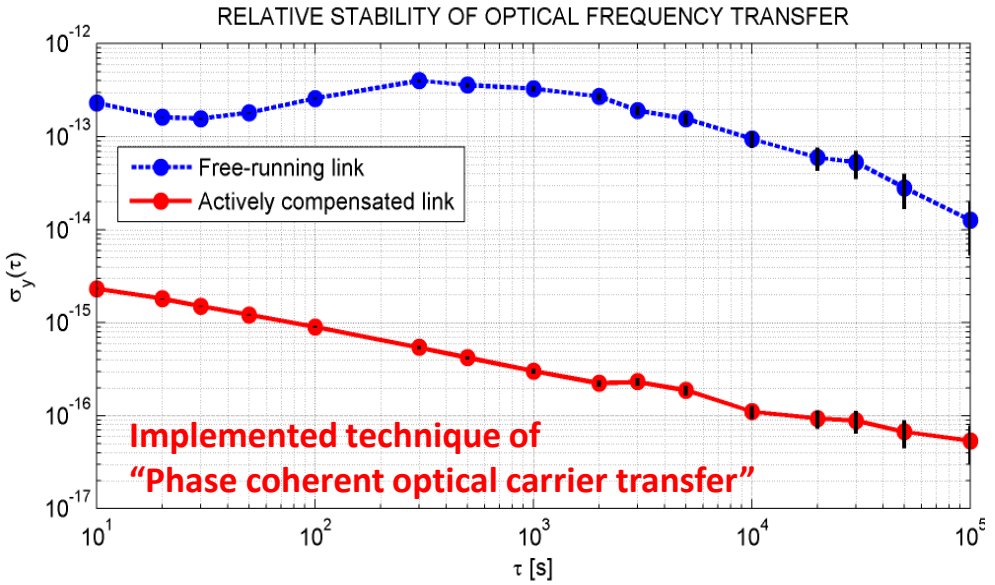


The frequency shift of laser C1540 nm due aging is cancelled by combination of control loops between H-maser, optical frequency comb and optical clock laser at 729 nm

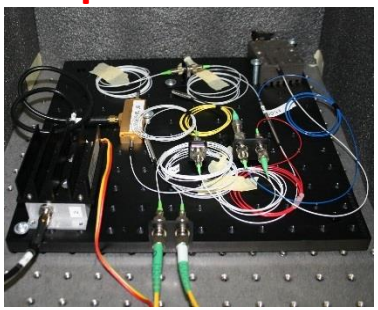
Optical carrier transfer from ISI to NPP Temelin (401 km)

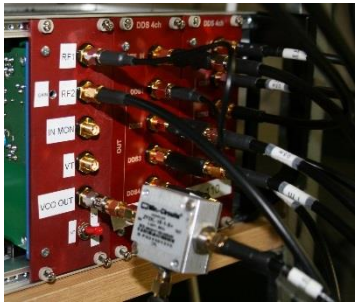
October 2018:

- finished set-up of bidirectional optical fibre link ISI/NPP Temelin by CESNET
- established optics and necessary electronics for the carrier coherent transfer
- Next steps – implementation for calibration of FBG sensory network optical reference



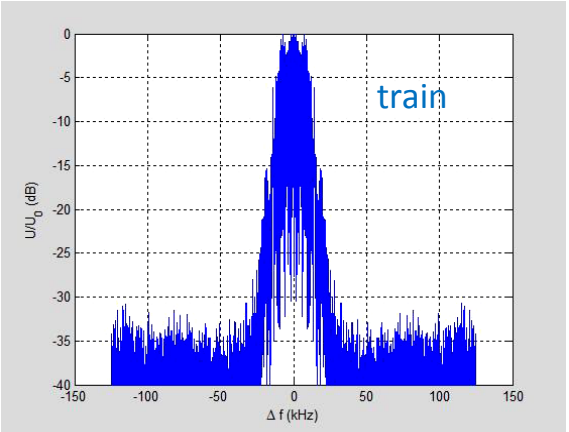
Optics and electronics (near end)

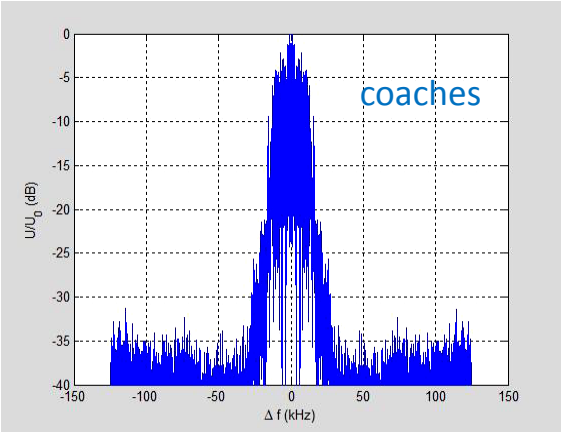




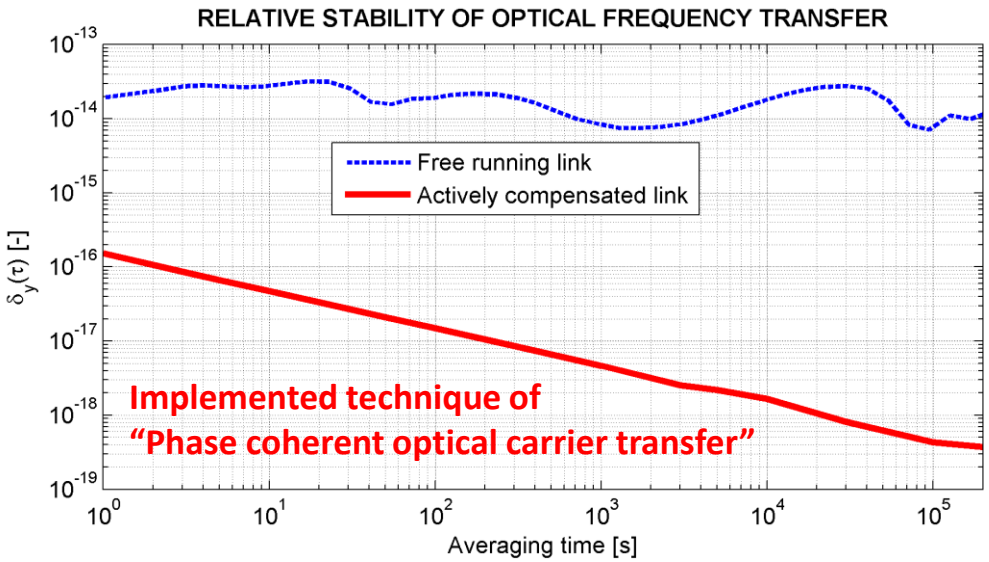
Optics and electronics (far end)

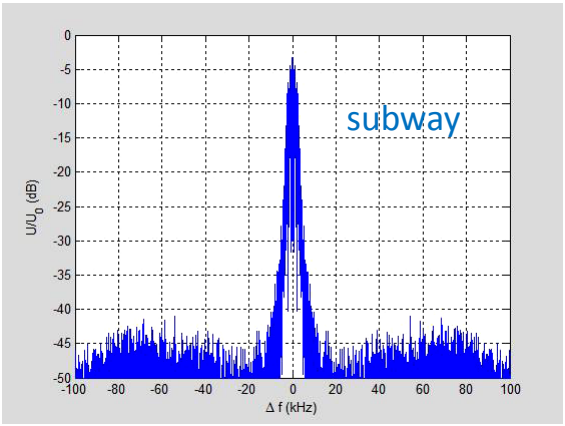
ISI – NPP Temelin in-loop beat (401km link)

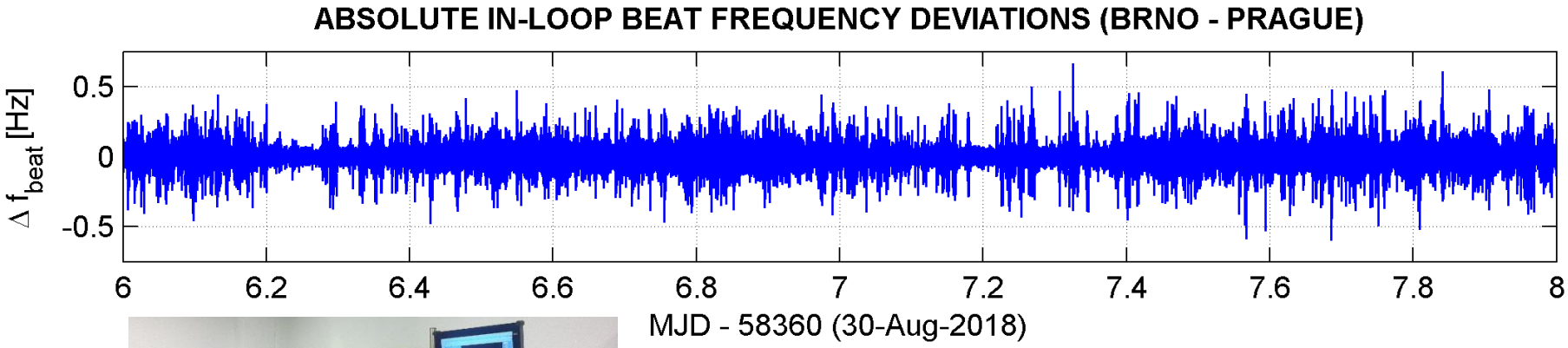


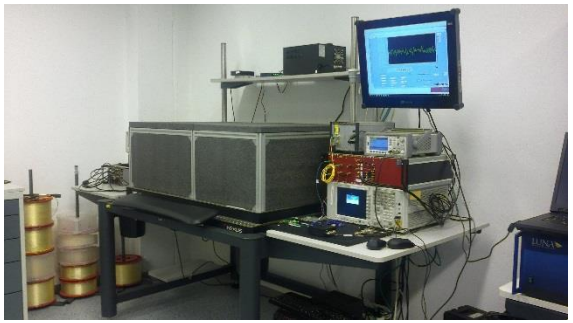


Optical carrier transfer from ISI to CESNET (306 km)









Planned tasks for the ISI-CESNET (Brno - Prague) link:

- Czech optical frequency scale (CMI, UFE and other labs)
- CESNET C2H2 optical reference calibration
- Reference for Institute of Nuclear Research (NPP service)

Acknowledgements

The authors also wish to express thanks for support to institutional support RVO:68081731. The optical source was developed thanks to support from Technology agency of the Czech Republic, project no. TA03010835. Technology of FBG measurement, preparation of FBG based optical sensors and method of measurement was supported from Ministry of Interior of the Czech Republic project no. VG20132015124.

Thank you for your attention

This project receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 731107

… and special thanks to:
Martin Čížek, Lenka Pravdová, Břetislav Mikel, Šimon Řeřucha,
Jan Hrabina and Josef Lazar, Department of Coherence optics, ISI
Josef Vojtěch, Ondřej Havliš and Vladimír Smotlacha, CESNET

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