Fibre Link for Optical Frequency Transfer between ISI and BEV

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***Abstract*— Our contribution presents the current state of operation and first experiments conducted on a recently established 232 km long Doppler-compensated fibre link between the Institute of Scientific Instruments in Brno (ISI), CZ and Federal Office of Metrology and Surveying in Vienna (BEV), AT, using communication infrastructure provided by CESNET. To demonstrate the link functionality, we measured phase noise power spectral density of a remote beat note of two independent lasers locked to high-finesse stable resonators. Using optical frequency combs at the both ends of the link, the long-term relative frequency deviation of local active hydrogen masers operating at ISI and BEV was estimated.**

Keywords—optical frequency transfers, fibre links, stabilization, comparison, laser, H-maser

I. Introduction

CESNET and ISI are operating an experimental fibre network for the dissemination of a stable optical frequency, Fig. 1. The ISI-BEV fibre link is the first operational segment of the planned delocalized composite clock network infrastructure – a coherent fibre link in which a stable optical oscillator (Hz linewidth) will be disseminated between ISI and BEV (232 km) and TU WIEN (additional 24 km).

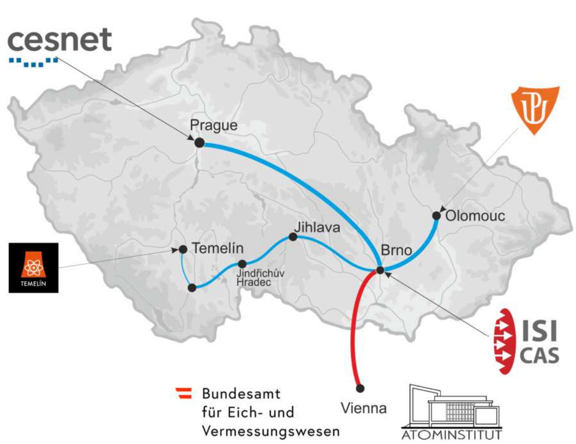

Fig. 1. Experimental fibre links for phase-coherent optical frequency dissemination currently (2021/03) operated by ISI and CESNET. The ISI-BEV link is highlighted in red.

Local super-coherent oscillators at each site will be synchronized using the link and connected to respective local clocks: a Ca^+ optical clock at ISI, a Cs clock at BEV, a Thorium nuclear clock at TU WIEN, [1].

II. Methods and Results

In our pilot experiment we are investigating a remote beat note of two independent highly coherent laser sources working at 1542 nm. A 1542 nm low-noise laser locked via an optically referenced optical frequency comb to a 1540 nm cavity-stabilized laser (ISI custom design) is being transmitted from ISI to BEV over a Doppler-compensated fibre link. In BEV, the beat note between the link output and a local 1542 nm cavity-stabilized laser (Menlo Systems ORS) is measured, Fig. 2.

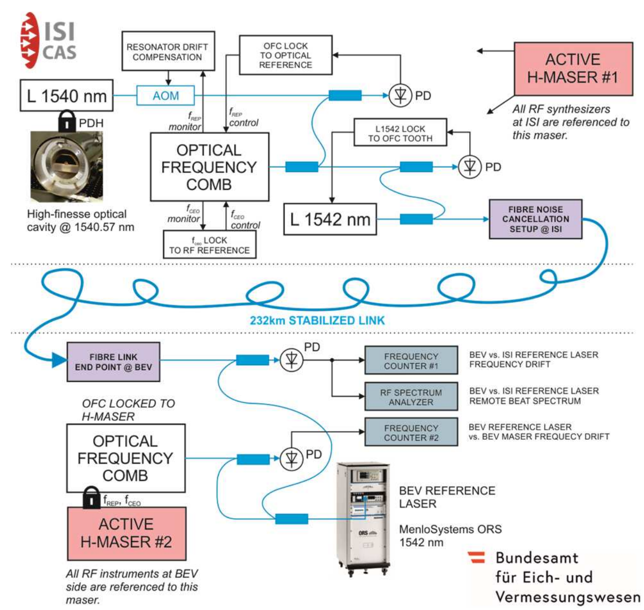

Fig. 2. Overall setup of the experimental 232 km long fibre link between ISI and BEV. Legend: AOM - acousto-optic modulator; PD - photodetector; L 1540 nm - Koheras Basik @ 1540 nm; L 1542 nm - Koheras Basik @ 1542 nm; blue - optical signals and components; black - electrical signals and components.

The link utilizes its dedicated channel in a DWDM multiplex. The fibre noise cancellation setup uses a general scheme based on a Michelson interferometer with compensation and end shifter AOMs, [2], [3], [4]. The fibre noise cancellation electronics is an ISI's custom design based on an analog I/Q demodulator, a loop filter realized by a digital signal processor (DSP) and a direct digital synthesizer (DDS) driving the compensation AOM.

A. Short-term Phase Noise Investigation

Fig. 3 shows the phase noise power spectral density (PN PSD) of the beat note between the output of the 232 km long link transmitting ISI 1542 nm laser and the 1542 nm BEV ORS. For comparison, the chart shows PN PSD for stabilized link, free-running link and a theoretical 5-Hz linewidth laser. Due to the roundtrip delay the maximum achieved control loop bandwidth is approx. 100 Hz. Under given conditions Doppler effect cancelation is most effective for Fourier frequencies below 10 Hz. The integrated RMS phase noise of the beat note in 1 - 10 Hz Fourier frequency interval is 317 rad for a free-running link and 1.3 rad for the compensated link. This is approximately the same amount of noise as produced by a laser with a linewidth of 5 Hz (shown for comparison).

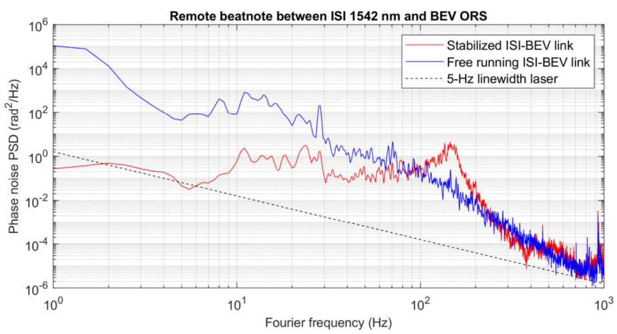

Fig. 3. Phase noise power spectral density of the observed beat note between the link end at BEV and the local ORS laser. Red: Doppler-compensated ISI-BEV link; blue: free-running link; dashed line: theoretical phase noise PSD of a 5-Hz linewidth laser.

B. Long-term Frequency Drifts Investigation

At both sides of the link, long-term drifts of local cavity-stabilized lasers are being monitored by beating with optical frequency combs referenced to local active hydrogen masers. At the ISI side this long-term drift is actively eliminated with a slow servo loop with integration time constant of 100 s, Fig. 3. At the BEV side the beats are processed by tracking oscillators with 10 Hz bandwidth and counted.

After subtracting the measured frequency drift of the BEV local laser from the remote beat note frequency we get the frequency drift of the comb teeth closest to the working frequency of the link. Fig. 4 shows the overlapping Allan deviations of this measurement. For integration times over 100 s the fractional frequency instability is dominated by the mutual drifts of the active hydrogen masers of ISI and BEV. It can be seen that for integration times greater than 10^4 s the overlapping Allan deviations are better than $7 \cdot 10^{-15}$, which is in agreement with the individual test reports supplied by the maser manufacturers.

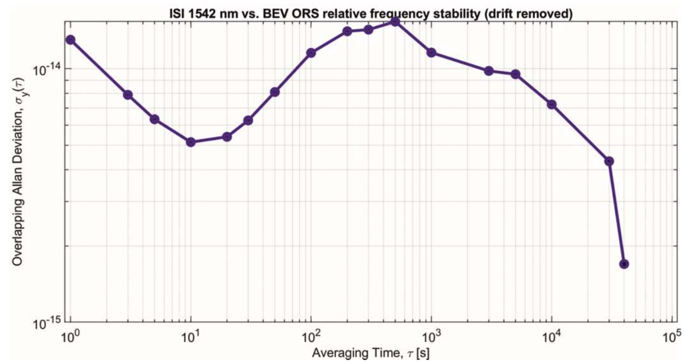

Fig. 4. After eliminating long term drifts of the lasers. The overlapping ADEV plot reveals the mutual long-term relative stability of the hydrogen masers that are referencing RF electronics at the both sides of the link.

III. Conclusions

We have shown that in is possible to investigate both long and short term phase/frequency noise of highly coherent lasers using our recently set up 232 km over-border fibre link between ISI and BEV. The link is ready for disseminating a stable optical frequency for quantum optic experiments.

Acknowledgment

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