High resolution characterisation of a 450-km-baseline GPS carrier phase link via optical fibre

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Sophisticated technology is used to compare distant atomic clocks by reception of Global Navigation Satellite System (GNSS) signals, or by sending signals in the microwave region from one location to another through geo-stationary satellites[1]. Further improvements will be required to support comparisons of optical atomic clocks, with their intrinsic fractional frequency uncertainty ~ 10^{-17}. To test and improve GNSS links, active hydrogen masers are useful tools, but for a fractional frequency instability below a few 10^{-15}, it becomes difficult to separate instability contributions from the masers and the GNSS link.

Here we use a 920 km optical fibre link, which we characterised before[2] at an uncertainty level below 10^{-18}, as a reference link for characterising a GPS carrier phase (CP) link. We simultaneously compare two active H-masers, via the fibre link and via GPS, over a baseline of 450 km. The masers are located at the endpoints MPQ in Garching and PTB in Braunschweig, see Fig.1. GPS antennas and receivers at both institutes are used for the maser comparison via the GPS link. At PTB, two different GPS receivers are used simultaneously, to study receiver dependence. All GPS data are processed using NRCan's Precise Point Positioning (PPP) service.

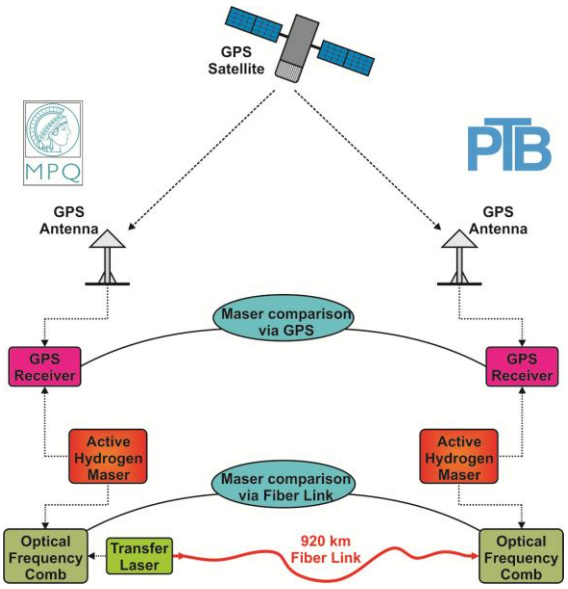

Fig. 1: Experimental set-up. Two hydrogen masers are compared via a reference fibre link, transferring a highly stable optical carrier frequency from MPQ in Garching to PTB in Braunschweig. Optical frequency combs on both sides connect optical and microwave frequencies. Simultaneously, the two masers are compared via a GPS CP link.

In a first measurement campaign (60 h data), both GPS link and fibre link revealed a mean fractional frequency offset between the two masers of ~1.4 x 10^{-14}. The *difference* between GPS link and fibre link data characterises the properties of the GPS link: this showed a statistically limited mean of $(0.01 \pm 2.6) \times 10^{-15}$.

We are now analyzing data from a second, longer campaign (~ two weeks duration), to reduce the statistical uncertainty. Our preliminary results indicate that the GPS link provided frequency information with a fractional frequency uncertainty below 10^{-15} at 200000 s averaging time.

[1] A. Bauch *et al*., "Comparison between frequency standards in Europe and the USA ...", Metrologia **43**, 109, 2006.

[2] K. Predehl *et al.*, "A 920-Kilometer Optical Fiber Link for Frequency Metrology at …", Science **336**, 441, 2012.