Sound creates light: German researchers transfer ultra-stable frequency across a 480-km-long optical fiber link

June 23 2010

Not only news, but also extreme precise optical frequencies can be transmitted across optical fiber links. Credit: GasLINE

German researchers at the Physikalisch-Technische Bundesanstalt have found an elegant solution to transmit an optical frequency with extreme precision: they employ fiber Brillouin amplification. The new method simplifies the comparison of newly developed optical clocks and it is likely to have applications in other areas where precise synchronization is needed, for example in radio astronomy. Experts in geodesy have already approached the PTB researchers with suggestions for joint projects.

When light is used to transmit information, well established techniques of optical telecommunications are available: modulated light pulses travel along optical fibers, become weaker due to optical attenuation in the fiber and are "refreshed" in signal regeneration stations along the way, where the signals are amplified and filtered. This goal becomes more demanding when the light itself - or more precisely, its optical frequency - is the information, and when this information is to be transmitted with extreme precision. Here conventional amplification techniques reach their limits.

Three researchers at Physikalisch-Technische Bundesanstalt (PTB) have now found an elegant solution: they employ so-called fiber Brillouin amplification, which is closely related to stimulated Brillouin scattering. The researchers inject pump light with a well-defined frequency into the far end of the fiber, so that the pump light travels in the opposite direction to the signal light, generating sound waves (acoustic phonons) in the glass fiber. The sound waves in turn scatter the pump light, enabling the existing signal photons to stimulate the emission of many more signal photons: thus a photon avalanche is created, which is kept going by the sound waves, and brings the frequency information to the remote end of the optical fiber with extremely small losses and very high precision.

The PTB researchers have already demonstrated this technique on a 480 km optical fiber link: the relative measurement uncertainty they achieved is equivalent to a deviation of one second in 16 billion years. Now they plan to span even larger distances. The new method simplifies the comparison of newly developed optical clocks, which possess such a high frequency stability that traditional methods for frequency and time comparison via satellite are no longer sufficient. The technique is likely to have applications in other areas where precise synchronisation is needed, for example in radio astronomy. Experts in geodesy have already approached the PTB researchers with suggestions for joint projects.

The PTB physicists Harald Schnatz and Gesine Grosche are internationally leading experts in the precise measurement and transmission of frequencies via optical fibers. They use the optical frequency of the light, with some $195 \bullet 10^{12}$ cycles per second, as the information. A first application of this new method was the remote measurement, conducted last year, of the so-called optical clock transition in a magnesium clock at the Leibniz University of Hannover. The scientists determined the characteristic frequency with which very cold magnesium atoms can be excited to a particular long-lived state, by a measurement from PTB via 73 km optical fiber. It is important to measure such frequencies accurately as they can in principle be used to "generate" seconds. "For such measurements, there are femtosecond frequency comb generators at both ends, which produce a fixed phase relationship between the transmitted light and the frequency standards on site", explains Harald Schnatz. The frequency standards on site are the new magnesium clock in Hanover and an optical clock at PTB. The different frequencies of the two are synchronized with the aid of femtosecond frequency comb generators, which can be compared to a gear mechanism. Schnatz adds: "At first we were astonished how well this complete system works."

Now the researchers wanted to bridge larger distances and build a connection for joint experiments to the Max-Planck Institute for Quantum Optics (MPQ) in Garching - a link of 900 km fiber, which attenuates the light by the almost inconceivable factor of 10*20 if it is not amplified. Moreover, the fiber has to be passed through twice, because it is part of a huge interferometer; this is how the optical length of the entire link, which otherwise varies due to temperature fluctuations, is stabilized. Here, conventional amplification techniques reach their limits. "Our PhD student, Osama Terra, hit on the brilliant idea of using the Brillouin amplification in the fiber itself", says Gesine

Grosche: "This gives us several advantages at the same time: First, even very weak signals are still amplified; the signal power is multiplied by a factor of up to one million. Thus, we need considerably fewer amplifier stations. Moreover, it is possible to selectively amplify very narrow-band light signals." This is very advantageous for the testing of the narrow-band clock transitions of optical clocks.

The group immediately tested this concept on a deployed underground fiber link: in cooperation with the "Deutsches Forschungsnetz" (DFN) (German National Research and Education Network) and the GasLINE company, which together operate a German-wide fiber network. With only one intermediate amplification station, the ultra-stable frequency was transmitted over a record 480 km long fiber link - with a relative transmission uncertainty of only 2 parts in 10^{18}, which is equivalent to a deviation of about one second in 16 billion years. As a result, even a connection with the French partner institute of PTB in Paris now looks realistic - with a vision of working together on the best optical clocks in the future.

At the technical conference "European Frequency and Time Forum" (EFTF), the results also received recognition: Osama Terra won the Student Award of the EFTF for his contribution in the field of "Timekeeping, Time and Frequency Transfer". The results have been submitted for publication and are available on the "arXiv" preprint server. Currently, the three researchers and their colleagues at MPQ Garching are continuing to work frenetically on establishing a connection between their institutes. They want to deliver the ultra-stable reference frequency of PTB to the laboratory of the working group of Professor Theodor Hänsch, where elementary properties of the hydrogen atom are measured spectroscopically with very high accuracy.

More information:

-- O. Terra, G. Grosche, H. Schnatz: Brillouin amplification in phase

coherent transfer of optical frequencies over 480 km fiber. arXiv:1005.3925v1. arxiv.org/abs/1005.3925
-- Grosche, G; Terra, O; Predehl, K; Holzwarth, R; Lipphardt, B; Vogt, F; Sterr, U; Schnatz, H.: Optical frequency transfer via 146 km fiber link with 10−19 relative accuracy. Optics Letters, Vol. 34 Issue 15, pp. 2270-2272 (2009)

Provided by Physikalisch-Technische Bundesanstalt