Microwave Frequency Transfer over Optical Fibre

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Abstract Summary

We report on an optical fibre frequency transfer technique that avoids traditional group-delay actuation bandwidth- and range-limitations to deliver world-leading optical- and microwave-frequency transfer performance.

Keywords-Microwave frequency transfer; Optical fibre; Phase measurement

Time and frequency transfer via optical fibre has seen a great deal of development since the early work of the 1990s [1, 2]. Measurements of fluctuations of the transmitted signal's phase, resulting from environmental perturbation of the link, are used by a feedback loop to 'stabilise' the signal delivered to the remote user. Transfer techniques that transmit a single optical frequency have led to the longest links [3], and the highest transfer stabilities over shorter links [4]. However, for many applications, the transfer of a microwave-frequency signal (encoded as a modulation on an optical carrier) is preferred as it can be applied directly in electronic systems. A leading publication reports a transfer stability of 1×10^{-15} at 1 s over an 86 km urban link [5] for such a technique.

Unfortunately, all microwave-frequency transfer techniques require group-delay actuation of the fibre link in the form of fibre stretchers and/or thermal compensation spools. In real-world systems, this often results in lower feedback loop bandwidths (potentially leaving more uncompensated noise), and a smaller range of feedback (limiting the maximum practical link length). Recently, new dual optical- and microwave-frequency transfer techniques have emerged that combine the greater stability of optical-frequency transfer techniques with the increased versatility of the microwave-frequency transfer [6, 7]. Nonetheless, these techniques still depend on the aforementioned traditional group-delay actuation systems, thereby limiting their performance.

We report on a dual optical- and microwave-frequency transfer technique that avoids these traditional group-delay actuation systems, while maintaining optical-frequency measurements of fibre fluctuations, to deliver ultra-stable optical- and microwave-frequency transfers. This is achieved by generating two coherent optical frequencies (separated by the desired microwave frequency) at the transmission source and also using two independent feedback loops from two separate measurements of link fluctuations.

The first loop measures the average phase delay of the two optical frequencies, and feedback is applied using an acousto-optic modulator (AOM) as in the case of standard optical-frequency transfer techniques such as [4]. The AOM provides a large feedback bandwidth and also a large range of feedback. However, it applies the same phase correction to both optical frequencies, so any residual difference remains uncorrected.

The second feedback loop measures the differential phase fluctuations of the two optical frequencies, thereby effectively measuring the phase fluctuations of the microwave frequency. We use a bespoke bidirectional actuation device, based on a Mach-Zehnder interferometer that can alter the phase of only one of the optical frequencies, and thereby also alter the microwave-frequency phase. Our conference presentation will report on the performance of this technique deployed on an optical fibre link spanning several tens of kilometers across a metropolitan area.

With the inclusion of only a handful of additional telecommunications-grade components, we believe that most of the world's optical-frequency transfer links can be easily retrofitted to use our technique. This development creates the opportunity to increase the versatility and performance of existing and future fibre links and thereby drastically expand the scope of research in the dozens of high-impact science applications supported by optical fibre frequency transfer.

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