Dissemination of Optical Frequency for Future Telecom Networks and Applications

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***Abstract*—Optical atomic lattice clocks are a precise source for time with frequency accuracy to a few parts in 10^{-18}. The optical frequency from these clocks needs to be disseminated over a fiber to make them fit for different applications. The paper investigates a methodology for disseminating optical frequency over a fiber by sending the operative frequency as the beat frequency of a heterodyne signal. The work details results obtained using this technique for frequency transfer over several kilometers of fiber in the lab and real environment.**

Keywords—Optical lattice clock, optical reference system, allan deviation, acousto-optic modulator

I. Introduction

The transportable industrial based optical atomic clock is based on strontium atoms [1]. It is the next generation technology for precise time and frequency distribution. Optical clock technology comprises locking a laser to an ultra-stable optical cavity, which results in a laser with mHz linewidth. The laser beam is then used to probe a cloud of atoms which are cooled to few µK. These atoms are trapped in an optical lattice which aids to provide long term frequency stability to a few parts in 10^{-18}.

Future networks and applications demand stringent timing requirements leading to high accuracy requirements across networks. Additionally, there are applications in scientific domain that demand precise time. To cater for the increasing timing requirements, microwave based atomic clocks are evolving to optical atomic clocks, increasing the frequency stability from a few parts in 10^{-14} to 10^{-19}. Optical frequencies from these clocks need to be disseminated over a fiber with great precision and stability to make them fit for future applications. The experimental work details a novel methodology of transferring optical frequencies over a fiber. The method compares the technique over several kilometers of fiber spool in the lab with fiber over a test link.

II. Exerimental Setup

An optical reference system [2] was used for this experiment. The system resembles to an optical clock in operation. The optical reference system consists of a cavity and a frequency comb. The system is composed of a Fabry-Perot cavity that serves as the reference for a continuous wave laser. The cavity of the system is decoupled from vibrations and acoustically isolated, enabling the device to be handled well in rough environments. The optical frequency is fed to a frequency comb to generate a 10MHz signal. The optical output used for the experiment has a wavelength of 1542nm.

The experiment explores a frequency distribution technique using an interferometric design. In this method, the operative frequency is transmitted as the beat frequency of the heterodyne signal. The heterodyne signal is formed from two signals. When transmitted over the fiber, the noise affects both signals equally. The AOM (Acousto – Optic Modulator) causes the frequency of the continuous wave laser signal to increase by an amount equivalent to the frequency of the AOM. The combined signal has the two heterodynes, which is the sum and difference of two frequencies. The sum of the frequencies is out of the photodetector range; hence the photodetector only detects the difference of the two frequencies. At the receiver side, the frequency difference of both signals is extracted. The frequency difference of both signals is the beat frequency, which is largely unaffected by noise, hence achieving accurate synchronisation.

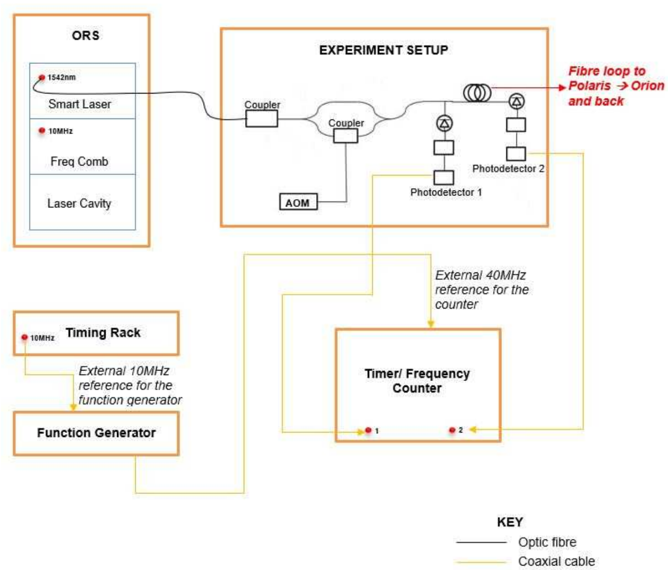

Fig 1: Experimental setup for the frequency transfer technique

The experiment was performed to understand the frequency stability when optical frequencies are disseminated across the fiber. The experiment was performed for several kilometers of fiber spools in the lab and over real fiber test link in the external environment. The test was done over 4km, 10km and 20km fiber spool and over a 4.8km fiber link. Each experiment was conducted for a period of 2 to 3 days, where frequency deviation was monitored. An Allan deviation graph has been plotted to analyze the frequency fluctuations over the period.

III. RESULTS AND DISCUSSION

The Allan Deviation graph was plotted to understand the frequency stability when optical frequency was disseminated over the fiber.

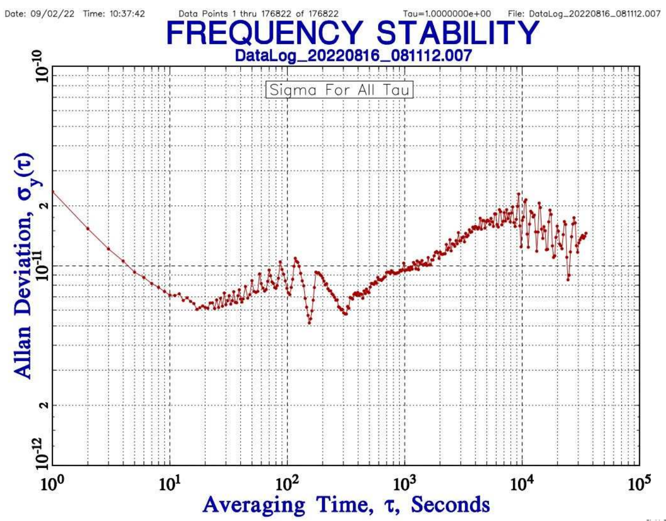

Fig 2: Allan Deviation plot for 4km fiber spool

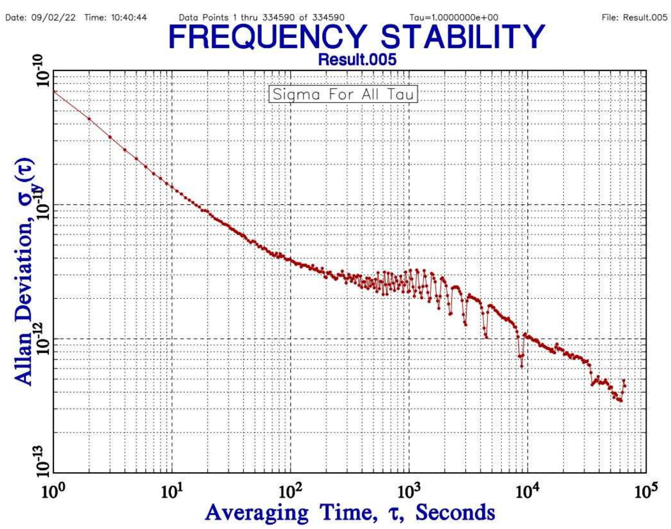

Fig 3: Allan Deviation plot for 4.8km fiber test link

The Allan Deviation plots compare the frequency stability for 4km fiber spool and 4.8km fiber test link. From the results, it is observed that the frequency stability is better in case of fiber over the real link compared to the fiber spool. The fiber is closely wound in case of fiber spool. Hence the adjacent fibers are very close to each other and tightly wound. This possibly causes the interference among adjacent fibers thereby causing frequency fluctuations. The 4.8km fiber test link is laid over the ground and they are properly insulated and not closely wound as in case of fiber spools. Hence, frequency fluctuations are less compared to the previous case which leads to better frequency stability. The optical frequencies were transmitted directly from the optical reference system without any amplification to boost the signal power. There were a few dB of losses over the connectors and patch panels but this was not high enough to degrade the signal quality over the specified length of fiber cable.

IV. CONCLUSIONS

The experiment was done to understand the behaviour of the optical frequency when it is disseminated across a fiber cable. The optical reference system is a clock with narrow linewidth 1542nm laser output ~1Hz. This work gives a base understanding on disseminating the narrow linewidth laser output from the optical clock over several kilometres of fiber to distribute time and frequency information at national level. The work will be expanded in the future to disseminate frequency over longer distances of fiber cable using a transportable optical clock to distribute time and frequency information at national level.

The fiber cable picks up small disturbances. As a result of these disturbances, frequency fluctuations were observed. Hence, this experiment will be modified to explore the potential in using an optical atomic clock for sensing applications as well.

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