Frequency transfer of optical standards through a fiber network using 1550-nm mode-locked sources

Kevin W. Holman, David J. Jones, R. Jason Jones, and Jun Ye
JILA, NIST and University of Colorado, Boulder, CO 80309
(303)-492-0667 (Voice) 303-492-5235 (Fax) kevin.holman@colorado.edu

Abstract: A 1550-nm mode-locked laser source phase locked to an optical atomic clock was used to transfer precise optical/radio frequency signals over a fiber network with ultrahigh stability.

With the advent of optical atomic clocks and the associated superior short-term frequency stability, transfer of signals linked to such clock/frequency standards over an appreciable distance with minimal loss of stability has become an important research subject. Using femtosecond (fs) frequency combs produced by mode-locked lasers for this purpose allows simultaneous transfer of optical and radio frequency (RF) signals, both phase locked to the optical frequency standard. Optical transfer is realized by detecting the absolute positions of the transferred comb lines, whereas RF transfer is achieved by detecting the repetition frequency of the transferred laser pulses. A mode-locked Ti:sapphire (Ti:s) laser can be directly linked to an optical standard, but its phase coherence must be transferred to a 1550-nm mode-locked source for distribution over optical fiber networks. We have achieved synchronization of repetition rates and coherent phase-locking of optical carriers between a 1550-nm mode-locked laser diode (MLLD) and a Ti:s laser [1,2]. Due to the lack of an orthogonal set of actuators to control the repetition and offset frequencies of the MLLD, its dynamics are explored to enable the design of an orthogonal control loop. A frequency-counting record of the beat between the Ti:s and MLLD offset frequencies (1-s gate time) determines an rms frequency fluctuation σ_{rms} of 3.2 MHz when the MLLD is free running versus σ_{rms} =1.5 mHz under locked conditions.

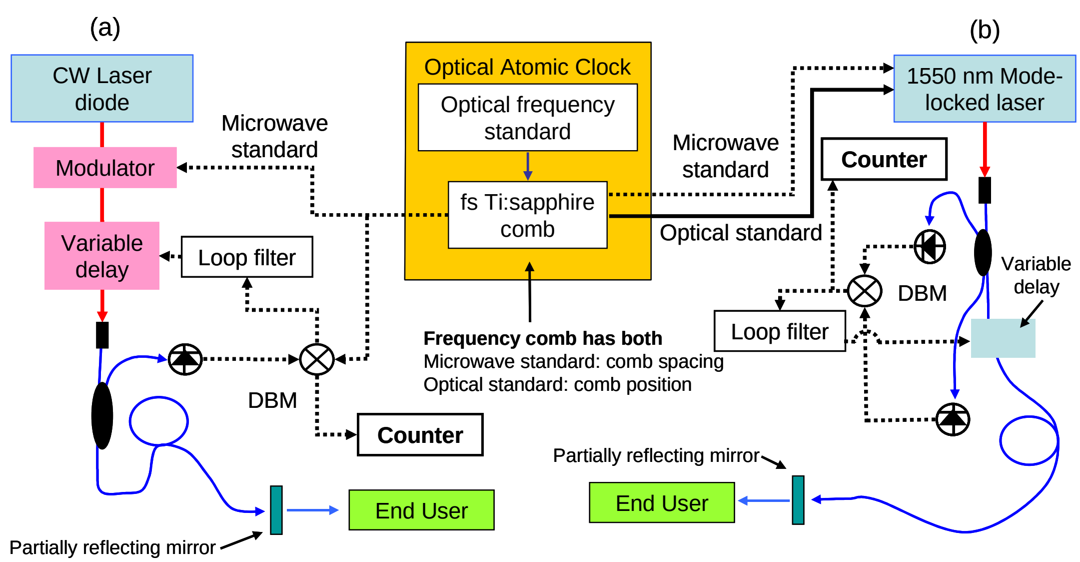

Fig. 1. Experimental setup for comparing (a) external modulation and (b) mode-locked pulse distribution of frequency standards. In each case, a portion of the transferred signal is returned to the transmitter for evaluation of the frequency stability. Optical paths are solid lines, microwave paths are dashed. DBM, double-balanced mixer.

Of course RF signals can be transferred via direct amplitude modulation on an optical carrier (Fig. 1(a)). Here we utilize the phase stabilized 1550-nm mode-locked laser source for simultaneous distribution of optical and radio frequency standards (Fig. 1(b)) over a 7-km installed fiber network. The transfer instability for the repetition rate of a 1550-nm mode-locked fiber laser is determined by comparing the pulse rate detected after transmission through a roundtrip of a fiber network with that of the pulses before transmission. To minimize the detection instability, it is critical to minimize the light power incident on the photodetector while maintaining a sufficient signal-to-noise ratio. The measured instability (Fig. 2) is the same as that for optical-carrier transfer, and is an order of magnitude better than that for RF transfer through modulation on an optical carrier [3].

A natural extension of this work in the time domain is to determine the rms timing jitter introduced during the transfer process. This will be an important step towards exploration of tight synchronization of remotely located pulsed lasers and radio frequency sources. We have also begun investigating optical transfer of frequency standards using mode-locked pulse trains. Preliminary results indicate there is no difference between cw and mode-locked schemes when measured locally. However, due to time gating and other effects we expect mode-locked pulses could offer a significant advantage over long transmission distances. We will present further work on this topic as well as implementation of stabilization loops for both microwave and optical frequency transfer using mode-locked sources.

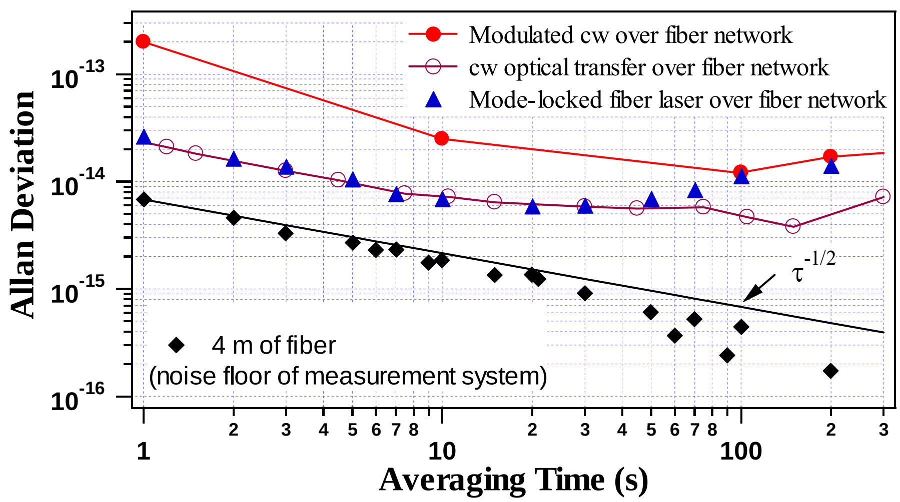

Fig. 2. Allan deviation showing instability of RF transfer of mode-locked fiber laser's repetition frequency, along with that for modulated optical carrier and cw optical carrier transfers. Measurement with a 4-m fiber represents measurement system's noise floor.

References:

1. D. J. Jones, K. W. Holman, M. Notcutt, J. Ye, J. Chandalia, L. A. Jiang, E. P. Ippen, and H. Yokoyama, Opt. Lett. **28**, 813 (2003).
2. K. W. Holman, D. J. Jones, J. Ye, and E. P. Ippen, Opt. Lett. **28**, 2405 (2003).
3. K. W. Holman, D. J. Jones, D. D. Hudson, and J. Ye, Opt. Lett., in press (2004).