OSA / CLEO/QELS 2010

CTuDD2.pdf

Atmospheric Delivery of a Microwave Clock using an Optical Frequency Comb

Ravi P. Gollapalli and Lingze Duan
Department of Physics, University of Alabama in Huntsville, Alabama, 35899, USA
Email: Lingze.duan@uah.edu, Tel: 258-824-2138, Fax: 256-824-3456

Abstract: Atmospheric delivery of a microwave clock using an optical frequency comb is tested over 60 m. Phase noise measurement shows a picosecond-scale rms timing jitter under various weather conditions. A strong amplitude-phase correlation is observed.

OCIS codes: (120.3930) Metrological Instrumentation; (060.2605) Free-Space Optical Communication

1. Introduction

Over the last few years, there has been an increasing interest in high-fidelity remote delivery of time and frequency references [1-4]. Among various schemes, using optical frequency combs (FCs) as the clock carrier for transmission appears to be very promising. This is largely due to the prospect of simultaneous transfer of multiple microwave and optical clock signals with one single FC system [2]. Experimentally, high-fidelity remote clock delivery in both optical and microwave regimes have been demonstrated based on fiber-optic transmission of FCs [1]. However, this fiber-based clock transfer scheme is ultimately restricted by its very nature of being *wired*. For many potential applications that require short-distance *ad hoc* clock distribution or clock transfer between mobile objects, such a scheme may not be the most cost-effective or even possible.

Recently, we have proposed the idea of using free-space FC transmission to deliver clock signals over short distances and have reported our experimental result on an indoor transmission link [5]. In the current presentation, we would like to report our latest effort to bring the transmission link to an uncontrolled outdoor environment, where the transmission-induced excess noise is much greater due to longer transmission distance, higher wind speed, and more diverse environment conditions.

2. Experimental Setup

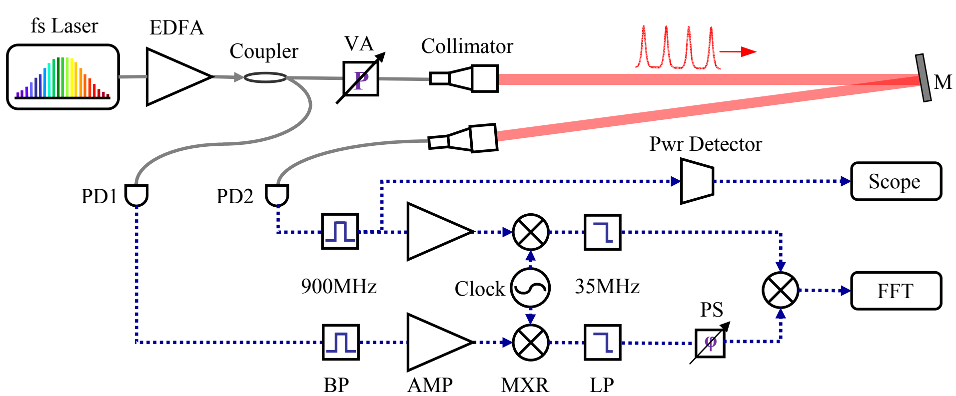

Fig. 1. Schematic of the outdoor transmission test system. AMP: microwave amplifiers, BP: band-pass filters, EDFA: erbium-doped fiber amplifier, LP: low-pass filters, M: silver mirrors, MXR: mixers, PD: photodetectors, PS: phase shifter, and VA: variable attenuator.

The phase noise measurement system is shown in Fig.1. A near-infrared femtosecond pulse train is generated by a commercial fiber laser (Precision Photonics FFL-1560), with an average power of 4 mW and a pulse repetition rate of 90 MHz. An erbium-doped fiber amplifier is developed to raise the average power to about 100 mW and shorten the pulsewidth to less than 100 fs. Part of the amplifier output is directly coupled into a high-speed photodetector (Thorlabs DET01) with a 2-GHz bandwidth. The majority of the optical power passes through a fiber-coupled variable attenuator before being coupled into a beam launcher, where it is collimated into a 7 mm-diameter beam. The beam launcher is located on the rooftop of the Optics Building on the campus of the University of Alabama in Huntsville. The four-floor building has an observation platform on its top and has no high-rise building around it, making it an ideal location for laser beam transmission test. A 2-inch gold mirror mounted on a sturdy fixture located at the other end of the platform sends the beam back into a fiber collimator (see Fig. 1), where the optical

CTuDD2.pdf

power is collected by an identical second photodetector. The total transmission distance of the beam is about 60m. Both the reference signal and the transmitted signal are bandpass-filtered at 900MHz to select the 10th harmonic of the repetition rate and then mixed down to 35 MHz by a local clock to further enhance the side-mode rejection. They are subsequently phase compared at a double-balanced mixer working in quadrature and the resulted phase fluctuation signal is frequency analyzed by a fast Fourier transform analyzer (SRS SR785). In addition, to assess the scale of the power fluctuation of the transmitted signal, a portion of the 900 MHz power in the transmission arm is coupled into a microwave power detector, which is monitored by an oscilloscope.

3. Result and Discussion

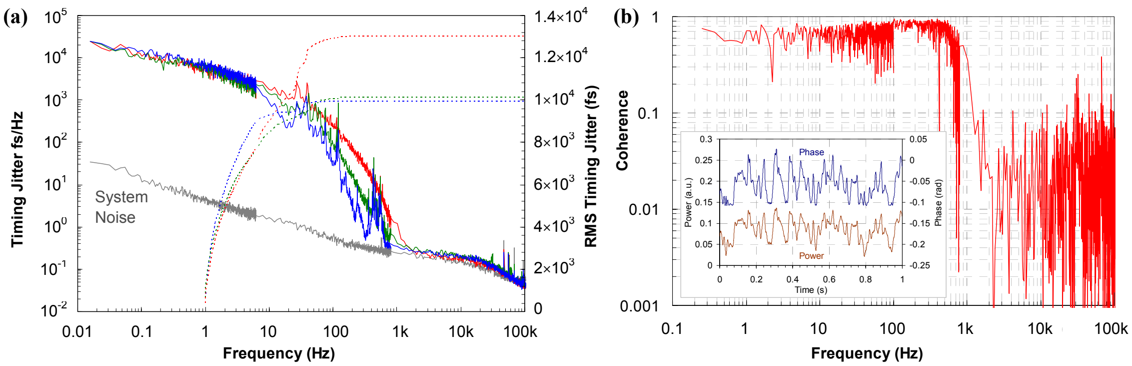

Fig. 2. (a) Typical timing jitter spectra at different wind speeds and their corresponding integrated rms timing jitter. Top (red) at 3.5 m/s. Middle (green) at 1.3 m/s. Bottom (blue) at 0.4 m/s. **(b)** The measured coherence function between phase noise and the received power fluctuation. **Inset**: typical time-domain traces of phase and power fluctuations over 1 s.

The phase noise measurement has been conducted at different times of a day under various weather conditions (except rainy or foggy days) during the month of November. It is observed that direct sunshine over the outdoor transmission path often corresponds to greater phase noise compared to overcast and evening. This is likely due to the ascending airflow caused by the heating of the roof under the sun. When the sun is not the major factor, wind speed appears to have a substantial impact on the behavior of the noise. Fig. 2(a) shows three typical phase noise traces, taken in late afternoons or evenings, along with the system noise (all in the form of timing jitter [2]) within a Fourier frequency range of 0.01 Hz – 100 kHz. The excess phase noise rises above the system noise at frequencies below 1 kHz. The power law of the noise spectral density appears to be f^{-4} at higher frequency but gradually tapers down to f^{-1} below 10 Hz. A correlation between the phase noise (1 Hz – 1 kHz) and the wind speed is evident in Fig. 2(a). The spikes around 30 Hz and 500 Hz are likely due to the mechanical resonances of the outdoor mounting structure. Fig. 2(a) also shows the integrated rms timing jitter for all three cases. The total rms timing jitter over 1Hz – 100 kHz is in the order of 10 ps, which is two orders of magnitude greater than the indoor result [5].

Scintillation is generally a major factor affecting the quality of free-space optical communication links [6]. In our experiment, both temporal scintillation (twinkle) and spatial scintillation (speckle) are visually observed. It is then conceivable that scintillation could have a direct impact on the excess phase noise. To quantify such an effect, we studied the correlation between the temporal fluctuation of the transmitted clock phase and the fluctuation of the received clock amplitude (by measuring the power of the 900 MHz clock signal). A pair of the typical time-domain traces of the phase and the power is shown in Fig. 2(b) inset. Their similar shapes indicate a strong correlation between phase noise and scintillation. The coherence function between phase and power is shown in Fig. 2(b). It is clear that the two channels maintain a high degree of coherence below 1 kHz, when the excess phase noise is above the system noise, and virtually have no coherence above 1 kHz, when the system noise dominates. Such an evident correlation indicates a direct coupling between the phase and the amplitude of the transmitted clock signal. The exact reason for this coupling is not completely clear at the moment. Our preliminary tests have excluded the effects of the microwave system and identified the photodetector as a possible source of this coupling. Work is also in progress to reduce the impact of scintillation by increasing the effective aperture of the detector.

4. Reference

[1] K. W. Holman *et al.*, “Remote transfer of a high-stability and ultralow-jitter timing signal,” Opt. Lett. **30**, 1225-1227 (2005).

[2] S. M. Foreman *et al.*, “Remote transfer of ultrastable frequency references via fiber networks,” Rev. Science Instrum. **78**, 021101 (2007).

[3] N. R. Newbury *et al.*, "Coherent transfer of an optical carrier over 251 km," Opt. Lett. **32**, 3056-3058 (2007).

[4] F. L. Hong *et al.*, “Measuring the frequency of a Sr optical clock using a 120 km coherent optical transfer,” Opt. Lett. **34**, 692-694 (2009).

[5] A. Alatawi *et al.*, “Radio frequency clock delivery via free-space frequency comb transmission,” Opt. Lett. **34**, 3346-3348 (2009).

[6] L. C. Andrews and R. L. Phillips, *Laser beam propagation through random media, 2nd Ed.* (SPIE Press, 2005).