Optical time and frequency transfer over a kilometer free-space link

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Applications in the fields of navigation and positioning, deep space exploration, etc. have demonstrated the demand for free-space time-frequency transfer technology. The traditional satellite based time and frequency transfer is limited at the nanosecond level, which is not enough for the after-mentioned applications. Here we propose a high-precision time-frequency simultaneous transmission over a 1.2 km free-space link. The free-space link is shown in Fig. 1(a), and a 1.2-km round-trip link is built between points at the Shanghai Jiao Tong University. Fig. 1(b) demonstrates the experimental test scheme, where time and frequency signals with a strict timing relationship are always modulated to the same wavelength of light to maintain the consistency of the time delays between two types of signals. The time interval between the local time signal T_s and the backhaul time signal T_{rt} can be expressed as $2NT_0 + \delta t$, with T_0 being the period of the frequency signal. $2NT_0$ can be measured accurately by the time signal, while δt needs to be measured accurately by the frequency signal. We can calibrate the N by adopting the coarse time interval measurement method. To significantly increase the precision of the time transfer, δt is measurd by the radio frequency's phase measurement.

We stabilize the link using a microcontroller-controlled optical delay line (ODL)and a commercial PID servo controller module-controlled PZT fiber stretcher, respectively, which has a higher compensation bandwidth, and the corresponding stabilization results are shown in Fig. 1(c), which achieves the optimum frequency stability of the 1.34 $\times 10^{-12}$@1s, 9.01×10^{-16} @1000s. The higher compensation bandwidth makes the system more stable, which is also evidenced in the phase noise PSD results shown in Fig. 1(d). The coarse time interval measurement results are shown in Fig. (e) and (f). The jitter peak-to-peak value of the coarse time interval measurement does not exceed 300 ps, which is better than the period of a 1 GHz frequency signal, so it is fully capable of measuring the value of N. By adopting the frequency phase measurements δt, the short-term stability of time transfer over 1 s is improved by two orders of magnitude to sub-picosecond level compared to the time signal. The results show that this scheme has the strength to realize time transfer on the order of picoseconds or even sub-picoseconds.

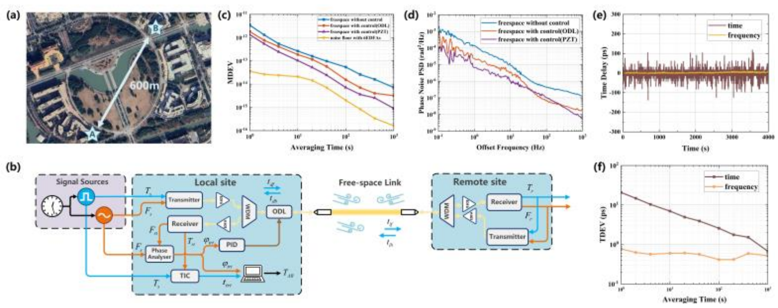

Fig. 1: (a) The 1.2 km round-trip free space link. (b) The block diagram of the experimental test of the time-frequency simultaneous transmission scheme. (c) Measured frequency stability (modified Allan deviation). Blue curve, free-running; red, control with ODL; purple, control with PZT Fiber stretcher; yellow, noise floor. (d) Phase noise power spectral density (PSD) results. (e) Measured time delay jitter. Brown curve, time result; yellow, frequency result. (f) Measured time stability of the time signal and the frequency signal in terms of time deviation.