Letters

Time Transfer Using the Phase of the GPS Carrier

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Abstract—**We report on tests of time transfer using the phase of the GPS carrier. The first set of experiments used two clocks connected to independent GPS receivers with closely-spaced antennas. The second set of experiments compared a clock at NIST in Boulder with one at the US Naval Observatory in Washington, DC.**

I. Introduction

Most laboratories transfer time using measurements of the GPS time-code observed simultaneously at two different locations ("common view"). This technique cancels or attenuates common-mode fluctuations, but the relatively low chipping rate associated with the Standard Positioning Service code (1023 kHz), limits the resolution of the method. The frequency of the carrier is roughly 1000 times higher than that of this code, so that time-difference measurements using the carrier phase have much greater resolution in principle.

As with conventional code-based time transfer, the two stations observe the same satellites at the same time. Each station measures the phase differences between the local clock and the received carriers. The parameters of the clock at each station are estimated after the data have been corrected for the geometric path delays between the station and the satellites and for the ionospheric and tropospheric refractivity. Unlike code-based time transfer where the measured transit times from the satellites to the receiver are unambiguous, carrier phase data include an unknown multiple of 2π radians, representing the initially unknown integral number of wavelengths in the path from each satellite to the receiver.

II. Experiments

In our first set of experiments, two clocks were connected to two GPS receivers with closely-spaced antennas. The time differences between the clocks were measured every 12 minutes by an independent measurement system and were also estimated using carrier phase data from the receivers. Carrier phase data were acquired every 30 seconds for about 28 days; we analyzed these data using the GIPSY software system [1]. We used satellite positions computed by the International GPS Service (IGS); such orbits typically have a radial accuracy of 5 to 10 cm [2]. We also estimated the water-vapor component of the tropospheric path delay using a single time-dependent parameter at the zenith combined with a random-walk noise model [3]. We were able to remove nearly all of the ionospheric delay by combining the measurements made at the L1 and L2 GPS frequencies.

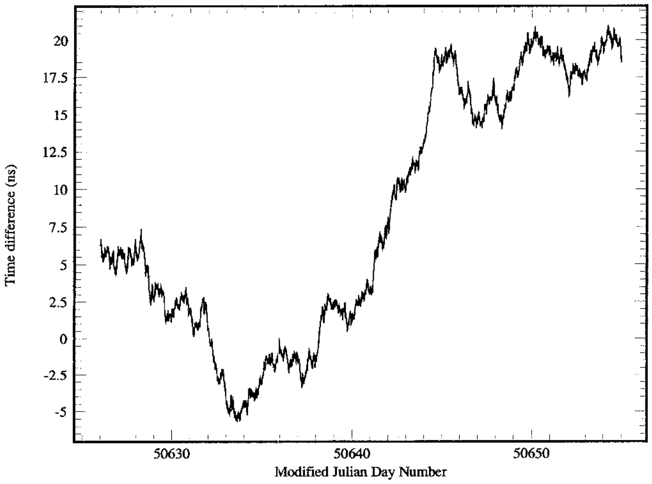

Fig. 1. The time difference between two clocks at NIST as measured by conventional hardware.

Fig. 1 shows the time differences between the two clocks reported by the measurement system. Fig. 2 shows the differences between the data of Fig. 1 and the corresponding carrier phase estimates. The 28-day period has been broken into four segments for convenience. The RMS amplitude of each of the four segments is shown in Fig. 2. The systematic daily variation in the residuals is almost certainly due to multipath effects. A similar short-baseline experiment was also performed at the US Naval Observatory. The time differences between two masers as measured directly and as computed using the carrier phase data are shown in Fig. 3. These residuals are somewhat smaller than those obtained at NIST, presumably because multipath effects are less serious at the USNO sites.

In our second set of experiments we used receivers at the US Naval Observatory in Washington, DC and at the NIST Boulder laboratories—a baseline of about 2400 km. Each receiver was driven by a commercial hydrogen maser whose performance was monitored using other clocks at each site.

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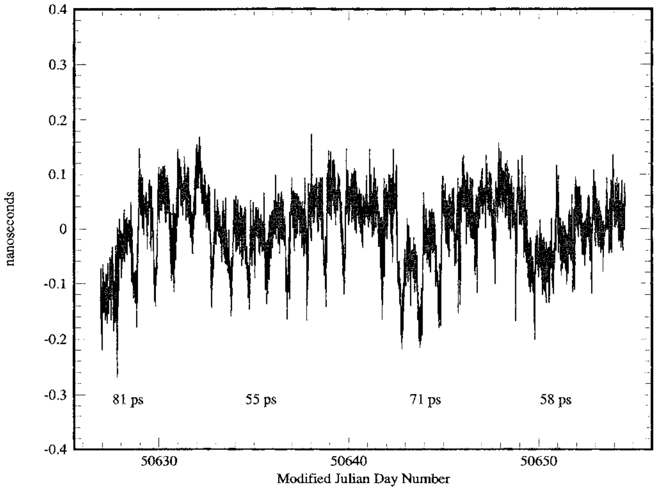

Fig. 2. The difference between the data of Fig. 1 and the corresponding carrier phase estimates. The RMS amplitude of each of the 4 weeks of data is shown.

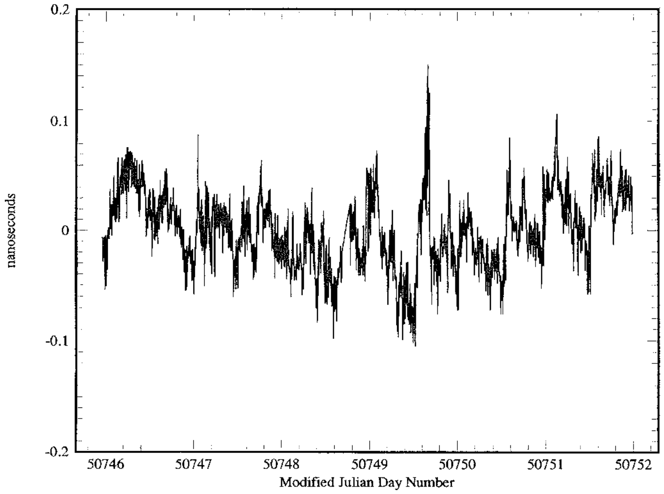

Fig. 3. The difference between a direct measurement of the time difference between two masers and the carrier phase estimate. The experiment was performed at the USNO. The RMS amplitude of these residuals is 35 ps.

The fluctuations in the time differences between the masers measured using the carrier phase link are comparable to the noise in the local observations, suggesting that the measurements are limited primarily by clock noise. Fig. 4 compares the carrier phase estimates with those made using conventional GPS common-view and two-way satellite time transfer between the same two sites.

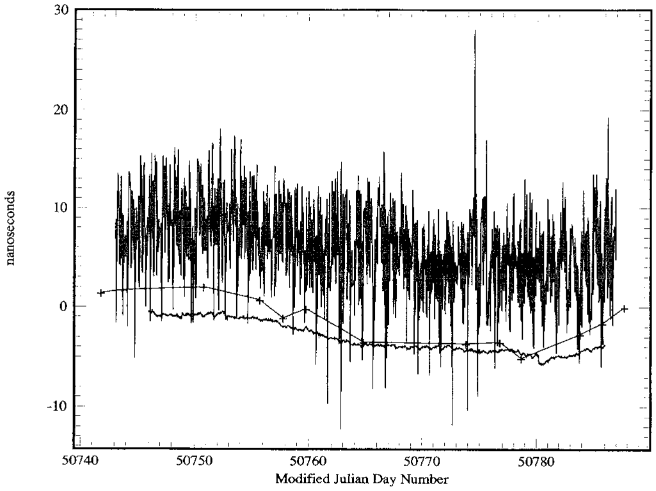

Fig. 4. The time difference between masers at USNO and NIST. Conventional common-view (top trace), two-way satellite time transfer (middle trace, with symbols), and the carrier phase result (bottom trace). The bottom plots have been offset for clarity.

III. CONCLUSION

These results suggest that the technique will be capable of distributing time with an uncertainty of about 100 ps and frequency with a fractional uncertainty of about 10^{-15} using an averaging time of about 1 day.

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