REAL-TIME ACCURATE TIME TRANSFER AND FREQUENCY STANDARDS EVALUATION VIA SATELLITE LINK LONG BASELINE INTERFEROMETRY

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Radio interferometry on natural sources which has been an important radio astronomy technique, requires two connections between the antennas; a data link and a local oscillator synchronization link. For baselines of up to a few kilometers, these connections are made by cables, and for up to about 50 kilometers by direct microwave link. Radio interferometry over longer distances has used the "VLBI" technique, which records the two data streams on magnetic tape for later correlation and uses independent atomic frequency standards at each station. An alternative method for long-baseline interferometers is to use an artificial satellite as a real-time link between the two antennas. This method was first successfully demonstrated by our group in November 1976, and reported on at the 8th PTTI Conference. This report records the results of an experiment by our group conducted in February 1977 to demonstrate the feasibility of a real-time accurate time transfer. Observing sites at Green Bank, West Virginia (National Radio Astronomy Observatory) and Lake Traverse, Ontario (Algonquin Radio observatory) were used for the experiment. A communications satellite known variously as Hermes or CTS-1 was made available courtesy of the Canadian Ministry of Communications. Cesium beam time standards belonging to the U. S. Naval Observatory were transported to each site as an independent check on the accuracy of the time transfer; they were calibrated at the beginning and end of each trip. The actual experiment was performed on 20 February 1977 at 1955 UT, observing the natural radio source 3C84 at 2.8 cm wavelength. The measured delay was observed in real time at the master station in Ontario by looking at the observed correlation on a cathode-ray display. The correlation output was also recorded on magnetic tape for later analysis. The raw measured time difference was ARO-GB = +470 nanoseconds. With our system bandwidth of 10 MHz, the correlation function was 100 nanoseconds wide, and its centroid could be determined with a precision of about 10 nanoseconds. This measurement was then corrected for the cable delays at each station, and agreed with that predicted from the cesium clocks to within 70 nanoseconds. This error could have been accounted for, e.g., by a 25 meter error in baselines or the relatively coarse cable delay measurements at Algonquin Radio Observatory. Bandwidth synthesis and accurate calibration techniques as described in Counselman et al. (1977) could be applied to yield real-time comparisons with an accuracy of a few nanoseconds. It should be noted that by transmitting sampled and clocked data the delay time of the satellite link does not enter into the measurement.

As an additional demonstration of the versatility of a real-time interferometer link, the stability of several different samples of atomic frequency standards was compared by substituting them in turn as master oscillators for the local oscillator at one station and observing the apparent dispersion in frequency of the interferometer fringes. This is known to be a very sensitive test of frequency standards because of the high multiplication involved. The results are displayed in figure 1. In each case a one minute averaging time was used. Resolution is 0.016 MHz, or about 6 x 10^{-13}. It will be seen that the H-P 5065A rubidium standard is close to the stability of a hydrogen maser over this period, while a cesium standard, even the "supertube" version, is appreciably poorer. These measurements did not test long-term stability. Also illustrated is an attempt to improve a cesium standard by using an external crystal idler instead of its internal crystal. This did not result in noticeable improvement; the same is true when the time constant of the servo loop was changed in a cesium standard equipped with this adjustment. We are continuing our satellite-link VLBI experiments. Our current objective is to use the satellite to provide a local oscillator link as well as a real-time data link. A two way path is required to correct for changes in the satellite position. Since the translation oscillator in the Hermes satellite is not phase coherent, the beacon signal from the satellite must also be used at each station to correct for the satellite oscillator phase. The use of the satellite link to correct the L.O. phase will provide much higher phase accuracy then previous VLBI techniques and should greatly ease the requirements on the frequency standards used.

1. S. H. Knowles, W. B. Waltman, N. W. Broten D. H. Fort, K. I. Kellermann, B. Rayhrer, J. L. Yen, and G. W. Swenson, "First Results from a Satellite Data Link Radio Interferometer", Proceedings of the 8th Annual PTTI Meeting, p. 529, November 30-December 2, 1976, NASA Doc. No. X-814-77-149.

2. C. C. Counselman, I. I. Shapiro, A. E. E. Rogers, H. F. Hinteregger, C. A. Knight, A. R. Whitney, and T. A. Clark, "VLBI Clock Synchronization", Proceedings IEEE, 65, 1622 (1977).

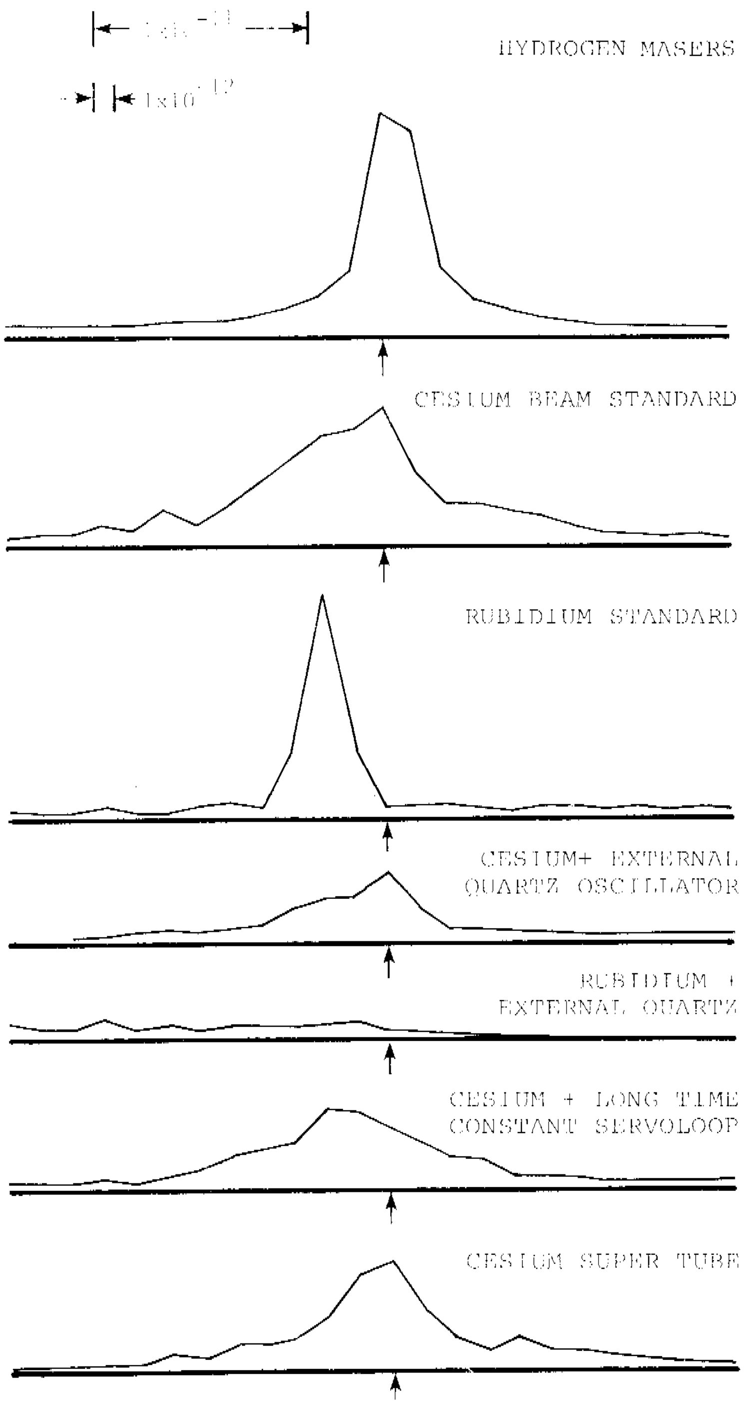

Figure 1. Comparison of frequency spread of various oscillators; 1 minute averaging time. In all cases a hydrogen maser was used for the other local oscillator.