# Two-Way Time and Frequency Transfer Using Optical Fibers

Steven R. Jefferts, Marc A. Weiss, J. Levine, S. Dilla, E. W. Bell, and Thomas E. Parker, *Fellow, IEEE*

***Abstract*—The National Institute of Standards and Technology (NIST) has built a two-way time-transfer device which uses any currently unused byte in the SONET (SDH) overhead to effect time transfer. The hardware shows stability which allows time transfer over short distances (km) with stabilities less than 10 ps. Time transfer over distances that require additional amplifiers in the fiber have not yet been investigated. Accuracy at the same level should also be possible.**

## I. INTRODUCTION

THE NATIONAL Institute of Standards and Technology (NIST) has developed a system which allows measurement of the stability of time transfer over a SONET (SDH) optical link. The SONET (SDH) protocol for data transmission is well established and, along with the growing need for improved synchronization in telecommunications systems, promises a vehicle by which improved synchronization can be achieved relatively inexpensively and robustly. Work on this type of system was begun by Kihara [1] who reported on two-way time transfer via SDH/SONET over a baseline of greater than 1000 km. The system uses a single overhead byte in each SONET frame to transfer timing data from the remote clock, as well as providing an on-time marker (OTM) which is used to transfer the actual time. The system described here is suited to use in a private network, and should allow construction of a time-scale with clocks separated by distances of kilometers.

## II. TWO-WAY TIME TRANSFER

Two-way time and frequency transfer is generally used to compare two geographically separated clocks. The clocks at each end of a link which joins them transmit the time of the local clock and receive the time of the remote clock. Each clock then measures the difference between the local clock and the remote clock. If the time difference data from the remote clock are differenced with the data from the local clock, then the path delay effects are removed, assuming that the path from the remote clock to the local clock is reciprocal with the path from the local clock to the remote clock. The time of the remote clock (clock 2) relative to the local clock (clock 1) can then be written as [2]:

$$\begin{aligned}\text{Time}(1) - \text{Time}(2) = 1/2\{&(TIC(1) - TIC(2)) \\ &+ (T_{x\,\text{delay}}(1) - R_{x\,\text{delay}}(1)) \\ &- (T_{x\,\text{delay}}(2) - R_{x\text{delay}}(2))\}\end{aligned}$$

where:

| | |
|---|---|
| TIC | Time interval counter reading for system $i$. |
| $T_{x\,\text{delay}}(i)$ | Transmit delay for system $i$. |
| $R_{x\,\text{delay}}(i)$ | Receive delay for system $i$. |

Accurate time transfer requires that the absolute magnitudes of the delays, $T_{x\,\text{delay}}$ and $R_{x\,\text{delay}}$, associated with the hardware on each end of the link be known and that those delays be temporally invariant. Accurate frequency measurements, however, require only that the delays be stable; the magnitudes need not be known. In the present experiment we are attempting to measure the temporal stability of these delays, which in general have instabilities associated with the environment (for example, temperature and power supply voltage) as well as delays associated with the digital hardware which may differ from one reset cycle of the equipment to the next.

## III. RESULTS

The basic hardware is diagrammed in Fig. 1. SONET overhead access is provided by the SONET Interface adapter [3]. This device, built around a framer chip [3] provides buffered access to both the received and transmitted SONET overhead. Start and stop commands for the time interval counter (TIC) are generated by the auxiliary timing board and overall system control is provided by the controller board.

In the first test, the system was configured for loop-back tests, as shown in Fig. 2. This configuration allows the measurement of the quantity $T_{x\,\text{delay}} + R_{x\,\text{delay}}$ combined with the delay associated with the fiber. The fiber used in this test is very short, about 15 cm, and is not expected to be a significant source of instability. The stability achieved using the configuration of Fig. 2 is shown in Fig. 3; the hardware stability exhibits an approximate flicker phase noise floor less than 10 ps, which is consistent with the flicker floor of the time interval counter used, the actual SONET hardware could be better than this. Both of the two systems used in this experiment are essentially identical and exhibit similar results in this loop-back test.

A full two-way test using 30 m of twin lead fiber was also conducted. In this test, the two ends of the link were

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The authors are with the National Institute of Standards and Technology (NIST) Time and Frequency Division, Boulder, CO 80303 USA.

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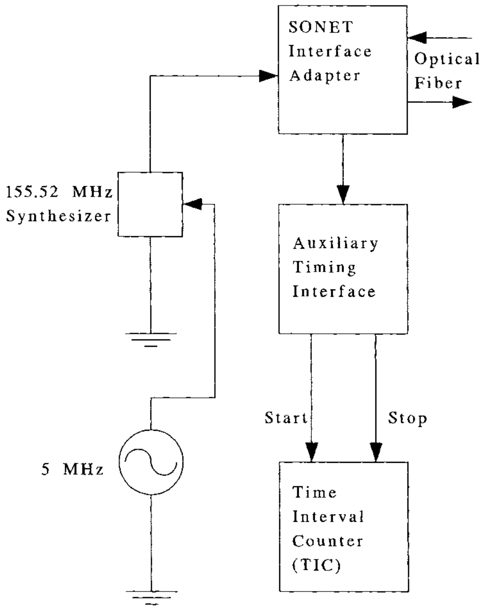

Fig. 1. Simplified block diagram of the SONET two-way time-transfer system.

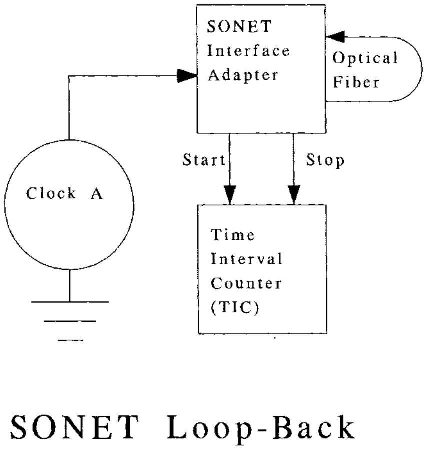

Fig. 2. SONET two-way time transfer system in loop-back mode. In this configuration the system measures the time between transmission and receipt of its own OTM.

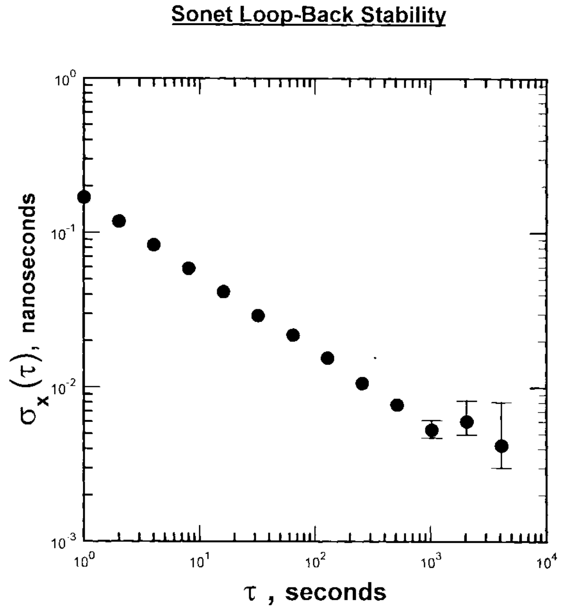

Fig. 3. Stability of the SONET two-way time transfer system in loop-back mode as described in Fig. 2.

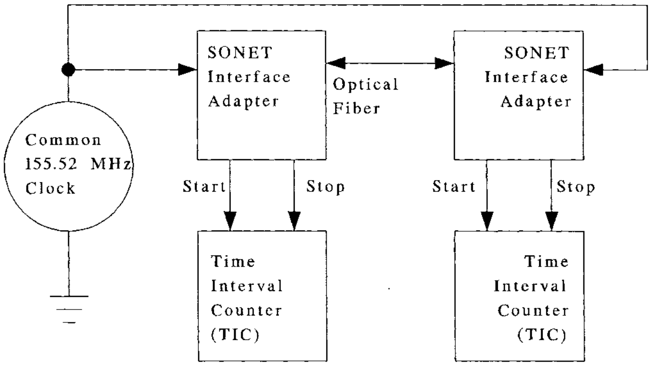

Fig. 4. Common clock two-way time transfer system designed to measure the stability of the hardware delays in the SONET two-way time-transfer system. The common clock arrangement removes clock noise from the measurement.

physically situated in the same environment, and the fiber was coiled between them. Further, the two SONET interfaces were driven from a common 155.52 MHz clock. The configuration is shown in Fig. 4. The resulting data, Fig. 5, exhibit instability of less than 10 ps at measurement periods greater than 1000 s, thereby allowing frequency transfer inaccuracy of less than $10^{-14}$ at times greater than 1000 s. Assuming the stability is not degraded by increasing distance, the observed stability should allow frequency transfer better than 1 in $10^{-15}$ at 1 day over distances on the order of 10 km. This assumption, in general, will probably not be valid for a public telecommunications system, but should be reasonable for a private network, where path reciprocity can be engineered into the system.

A study of the stability of two-way time transfer versus byte position in the overhead was also undertaken. The data show that the measured stability versus byte position for the four byte positions 12, 17, 26, and 73 in the overhead frame does not seem to depend on the byte position for this particular hardware configuration.

Preliminary study of the stability of the time-transfer process versus temperature was also undertaken. Temperature coefficients measured in the loop-back mode of operation measure the quantity $T_{x\,\mathrm{delay}} + R_{x\,\mathrm{delay}}$, while temperature coefficients measured in the two-way mode are sensitive to the quantity $T_{x\,\mathrm{delay}} - R_{x\,\mathrm{delay}}$. The temperature coefficients for this equipment using the above technique are $\delta T_{x\,\mathrm{delay}}/\delta T \approx 3$ ps/K and $\delta R_{x\,\mathrm{delay}}/\delta T \approx 44$ ps/K.

The stability of the hardware delays as a function of power supply voltage was also studied using the same technique to separate the $T_{x\,\mathrm{delay}}$ and $R_{x\,\mathrm{delay}}$ coefficients. The results of this study, shown in Fig 6. give $\delta T_{x\,\mathrm{delay}}/\delta V \approx -6.2$ ns/V and $\delta R_{x\,\mathrm{delay}}/\delta V \approx 0$ ns/V.

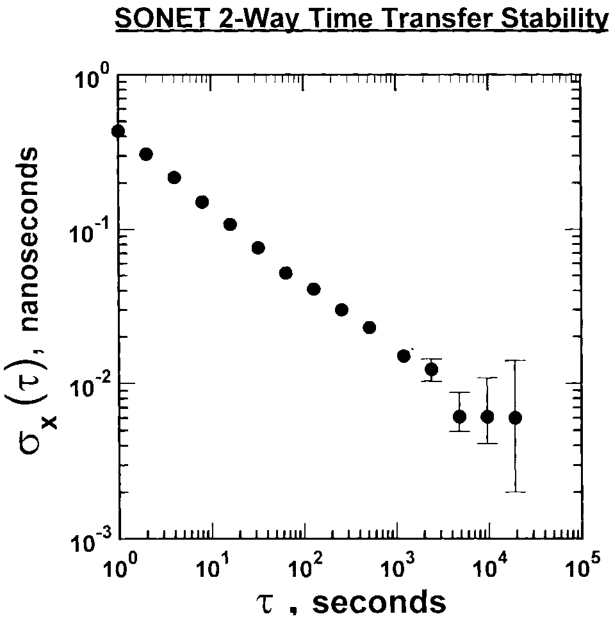

Fig. 5. The stability of the SONET two-way time transfer system in the common clock two-way mode described in Fig. 4.

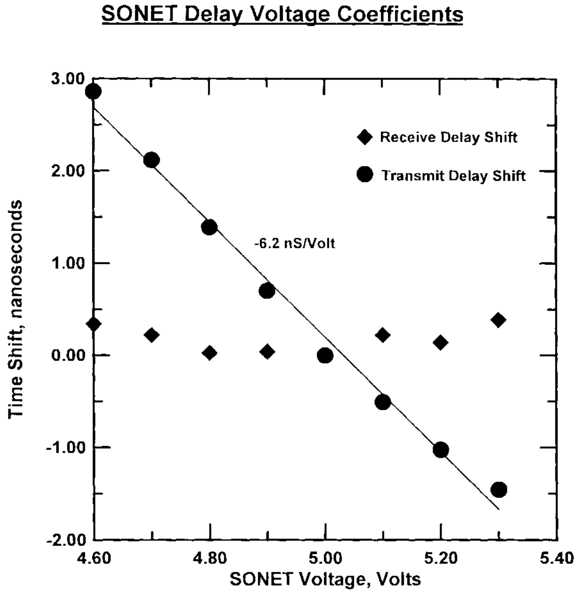

Fig. 6. The stability of the SONET two-way time transfer system as a function of power supply voltage.

## IV. CONCLUSION

Measurement of the stabilities achievable using two-way time transfer over a SONET/SDH OC-3 link at 155.52 MHz are on the order of 10 ps. The measurements presented here are measurements of the stabilities of the delays in the particular SONET terminals used and represent a lower limit on the stabilities with which this hardware could perform two-way time transfer in a real world situation. This system shows promise for allowing time-scales constructed from high-performance commercial cesium clocks to be constructed in situations where the clocks are separated by relatively large (≈kilometer) distances. Hydrogen maser time-scales would, most likely, show some degradation of the short term stability of the maser caused by the time transfer process.

## REFERENCES

[1] M Kihara and A. Imaoka, "SDH-based time and frequency transfer system," in *Proc. 9th EFTF*, Besancon, France, 1995, pp. 317–322.

[2] C. Hackman, S. R. Jefferts, and T. E. Parker, "Common-clock two-way satellite time transfer experiments," *Proc. 49th Annu. Symp. Frequency Control*, 1995, pp. 275–281.

[3] SONET Interface Adaptor: Odetics Inc. LIMO SONET Interface Adaptor. Framer Chip: PMC-Sierra Inc. The commercial equipment used has been identified for technical completeness only, to allow other researchers to duplicate the results contained herein. Other commercial equipment may perform differently, in particular it may be more or less suitable than the equipment described herein. Such identification implies neither recommendation nor endorsement by the National Institute of Standards and Technology.

**Steven R. Jefferts**, for a photograph and biography, see this issue, p. 208.

**Marc Weiss** received the B.S. degree from Valparaiso University, Valparaiso, IN, in 1973, the M.S. degree in mathematics in 1975, and the Ph.D. degree in mathematical-physics in 1981, both from the University of Colorado, Boulder.

He has been with the National Institute of Standards and Technology (NIST), Boulder, CO, since 1978. He designed and wrote the software for the NIST ionospheric measurement system. He has been active in studying and developing time transfer systems especially using the global positioning system. He has also specialized in new time scale algorithms, and in synchronization in telecommunications systems.

Dr. Weiss wrote the software for the NBS/GPS time transfer system for which he received the Applied Research Award of the NBS in 1983, along with the other principals.

**J. Levine**, photograph and biography not available at the time of publication.

**S. Dilla**, photograph and biography not available at the time of publication.

**E. W. Bell**, photograph and biography not available at the time of publication.

**Thomas E. Parker** (M'79–SM'86–F'94), for a photograph and biography, see this issue, p. 208.