TWO-WAY TIME TRANSFER THROUGH SDH AND SONET SYSTEMS[1]

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ABSTRACT

NIST has built a two-way time transfer device which uses any currently unused byte in the SONET overhead to effect time transfer. The hardware shows stability which allows time transfer at approximately 100 ps. Accuracy at the same level should also be possible.

INTRODUCTION

NIST has developed a system which allows us to measure the stability of time transfer over a SONET optical link. The SONET 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 greater than 1000 km baseline. 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.

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 simultaneously 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]:

$$\mathrm{Time}(1)-\mathrm{Time}(2) = 1/2\{(\mathrm{TIC}(1) - \mathrm{TIC}(2)) + (T_{xdelay}(1) - R_{xdelay}(1)) - (T_{xdelay}(2) - R_{xdelay}(2))\}$$

where

TIC(i) is the Time Interval Counter Reading for System i

$T_{xdelay}(i)$ is the transmit delay for system i

$R_{xdelay}(i)$ is the receive delay for system i.

Accurate time transfer requires that the absolute magnitudes of the delays, T_{xdelay} and R_{xdelay}, 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) as well as delays associated with the digital hardware which may differ from one reset cycle of the equipment to the next.

RESULTS

The basic hardware is diagramed in Figure 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

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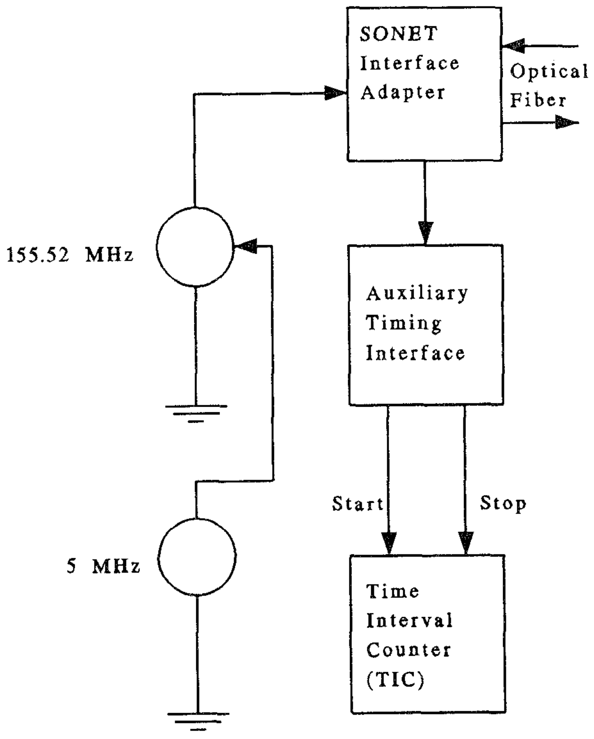

Figure 1. - Simplified block diagram of the SONET two-way time-transfer system.

(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, as shown in Figure 2. This configuration allows the measurement of the quantity $T_{xdelay} + R_{xdelay}$ 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 Figure 2 is shown in Figure 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. Both of the two systems used in this experiment are essentially identical and exhibit similar results in this loop-back test.

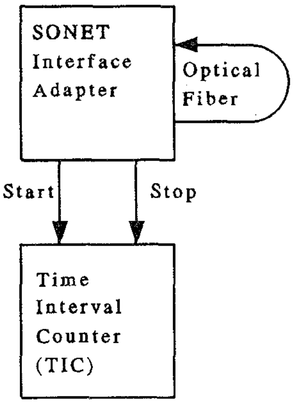

Figure 2. - SONET two-way time transfer system in loop-back mode. In this configuration the system measures the time between transmission and receipt of its own OTM.

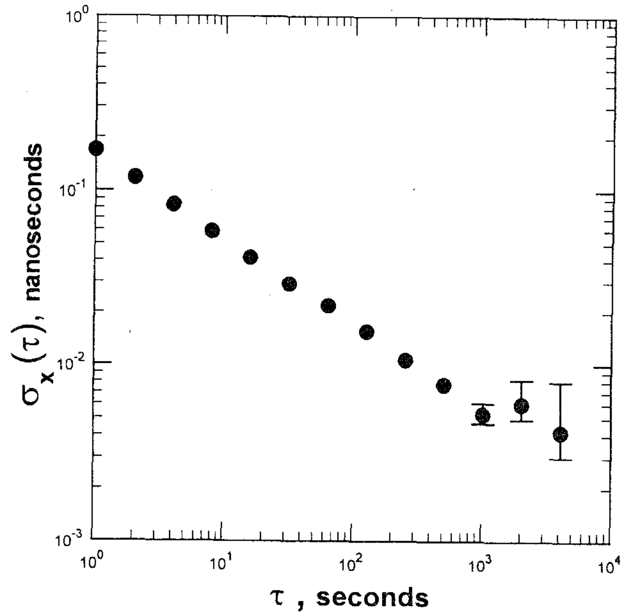

Figure 3. - Stability of the SONET two-way time transfer system in loop-back mode as described in Fig. 2.

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 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 Figure 4. The resulting data, Figure 5, while clearly less stable than the data from the loop-back test, still exhibit stability of less than 200 ps at measurement times greater than 10 s, thereby allowing frequency transfer of 10^{-11} at times greater than 100 seconds.

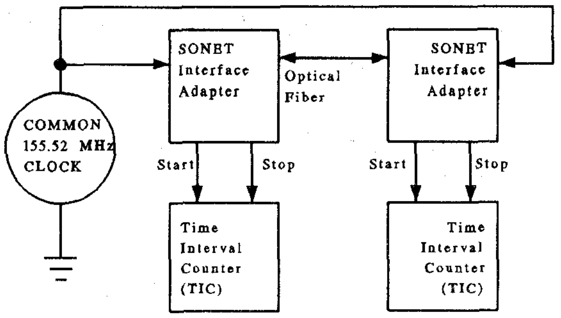

Figure 4. - Common clock two-way time transfer system designed to measure the stability of the hardware delays in the SONET two-way time-transfer system. The common clock arrangement removes clock noise from the measurement.

Assuming the stability in 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 100 km. This assumption will probably not, in general, be valid in a public telecommunications system, but may be possible in a private network, where path reciprocity can be engineered into the system.

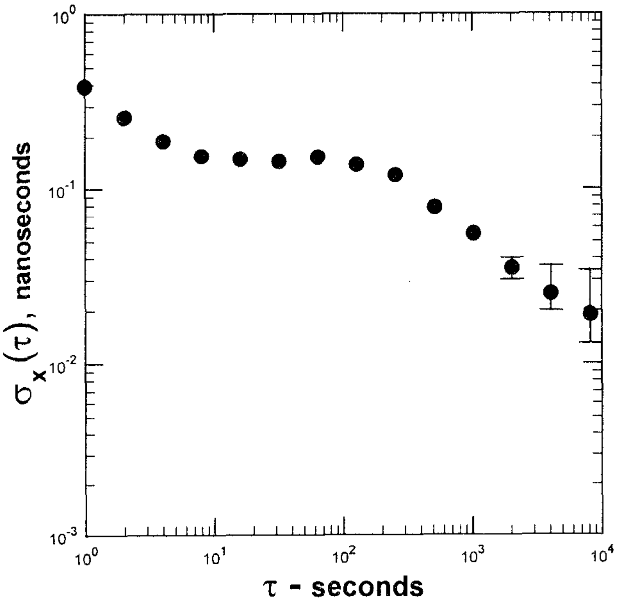

Figure 5. - The stability of the SONET two-way time transfer system in the common clock two-way mode described in Figure 4. The stability is better than 200ps at 10 s.

A preliminary study of the stability of two-way time transfer vs. byte position in the overhead was also undertaken. The data, shown in Figure 6, show the measured stability vs. byte position for the three byte positions 11, 17, and 26 in the overhead frame. The stability does not seem to be a function of the byte position for this particular hardware configuration. A very preliminary study of the stability of the time transfer process vs. temperature was also undertaken.

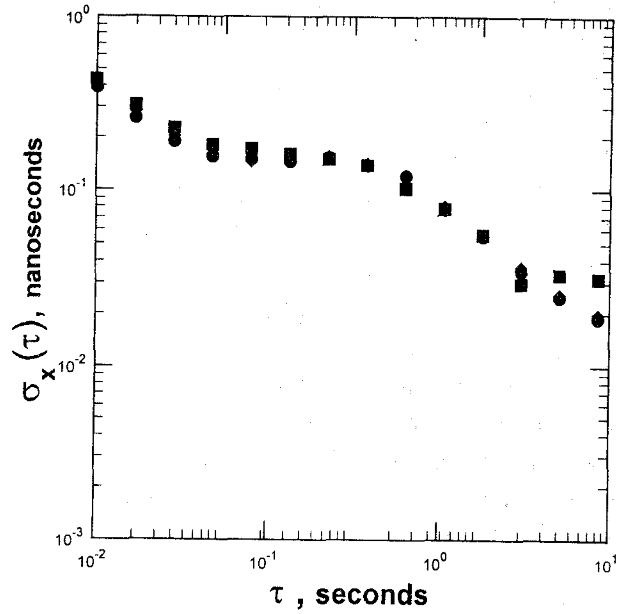

Figure 6. - The stability of the SONET two-way time transfer system as a function of byte position in the overhead. The solid circles are the stability measured for byte position 17, the solid diamonds are the stability measured for byte position 26 and the solid boxes are the stability measured for byte position 11.

Temperature coefficients measured in the loop-back mode of operation measure the quantity $T_{xdelay} + R_{xdelay}$, while temperature coefficients measured in the two-way mode are sensitive to the quantity $T_{xdelay} - R_{xdelay}$. The temperature coefficients for this equipment using the above technique are $\delta T_{xdelay}/\delta T \approx 3$ ps/°C and $\delta R_{xdelay}/\delta T \approx 44$ ps/°C.

MESSAGE FORMAT

The message format developed for this experiment uses only one byte of the overhead and transmits information to the remote end of the link in a byte serial format. The message format supports messages for the transmission of both absolute and relative time and frequency as well as administrative functions. The high-order bit of all bytes is 0, with the exception of the first byte of a block, where the high-order bit is set to 1, thereby identifying the start of a block. The next 7 bits of the first byte of a word are the word identifier, allowing the system to identify the type of data to follow. The first byte signals the start of a block, can act as an on-time-marker (OTM), and can be used as an idle character. The word format is such that all quantities are 32 bit unsigned numbers sent as 5 bytes, with the most significant bit first. The format thus looks like:

$Scccd_0d_1d_2d_3$, $Sd_4d_5d_6d_7d_8d_9d_{10}$, …, $Sd_{25}d_{26}d_{27}d_{28}d_{29}d_{30}d_{31}$.

The first 4 bits identify the type of number, and the dynamic range is 2^{32}. A variety of message types are defined, of which this experiment uses only two, the OTM and the idle character.

CONCLUSION

Preliminary 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 100 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. Further characterization of environmental sensitivities may, possibly, allow time transfer at the 10 ps level demonstrated by a single SONET/SDH device.

BIBLIOGRAPHY

[1] M Kihara and A. Imaoka, *Proc. of the 9th E.F.T.F.*, Besancon 1995.

[2] C. Hackman, S. R. Jefferts and T. E. Parker in *Proc. of the 49th Annual Symposium on 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 stable than the equipment described herein. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology.