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# TIME SYNCHRONIZATION VIA THE TRANSIT SATELLITE AT MIZUSAWA

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## ABSTRACT

Time signals emitted from Transit satellites have been received by the NACODE type receiver since 1974 at Mizusawa, Japan (station 027). By using these time signals, we can make a time comparison between the International Latitude Observatory of Mizusawa (ILOM) and USNO. To complete time comparison by this method, many corrections are, however, necessary such as propagation delays, a receiver delay, effects of relative motion of satellites, effects of the ionosphere and so on. Propagation delays are calculated from the precise ephemeris of the satellite (30190) supplied by the Topographic Center of DMA. The receiver delay is measured by supplying a simulated signal to the space near the receiving antenna. Effects of the ionosphere on the propagation delays may be the order of one microsecond. Standard deviations of each pass are estimated to be ±15.5 microseconds for the data UTC(ILOM)-UTC(USNO) obtained in December 1976.
Time comparisons by the Loran-C system between ILOM and USNO are referred for a check of the Transit satellite timing method.

## INTRODUCTION

Timing experiments via satellites have been carried out many times since 1962 (Blair 1974). In Japan also, experiments of time synchronizations between the Radio Research Labolatories (RRL) and the U.S.Naval Observatory (USNO) were carried out in 1965 and 1975 with accuracies of one microsecond and 10 nanosecond's order respectively (Frequency Standard Section and Kashima Branch 1965; Yamamoto et al. 1976). These experiments were made in the two way method and attained to the very high accuracy.

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This method is, however, much expensive and is not convenient for the frequent measurements.

Although the measurements via the Transit satellite (Navy Navigation Satellite) have relatively low accuracies as compared with the two way method, this method has the advantage that time comparison can usually be made twice a day at moderate expence. The Navy Navigation Satellites have been tracked by the TRANET I type receiving system since late 1974, and time information data in punched paper tape are available since 1976. In this report, timing analysis and various corrections which are necessary to derive time differences between UTC(ILOM) and UTC(USNO) are presented by using the data obtained in 1976. Time synchronization via Loran-C system will be referred to examine the consistency of these two methods.

## OUTLINE OF COMPARISON SYSTEM

Satellite trackings by measuring doppler shifts have been made with the rubidium oscillator as a frequency standard at the station 027. Time and frequency comparisons have been made between the rubidium atomic clock and UTC(ILOM) which is maintained by a cesium atomic clock. At the same time, satellite timing pulses are monitored by UTC(USNO) and the results are published regularly. Then, time differences between UTC(ILOM) and UTC(USNO) can be derived by using these data.

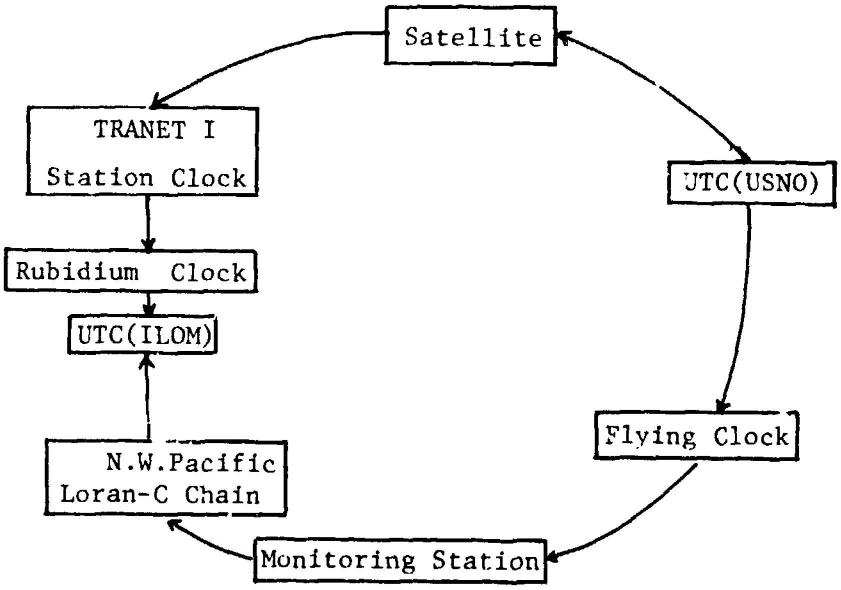

Fig. 1 Simplified block diagram of the time comparison system.

On the other hand, Loran-C signals of the Northwest Pacific chain are received at ILOM regularly with standard deviations of less than 0.1 microseconds. This chain (SS3) is monitored by flying clock from USNO. Thus we have another method of time comparisons between UTC(ILOM) and UTC(USNO). An outline of our time comparison system is shown in Fig. 1.

The TRANET I system receiver amplifies and demodulates signals from satellites, and demodulated signals are fed to the time burst detector which discriminates the satellite time marks. Time interval between this fiducial time mark and the station clock is measured to one microsecond.

## CORRECTIONS FOR PROPAGATION DELAY, RECEIVER DELAY, AND RELATIVE MOTION OF SATELLITE

As the orbital elements of satellites are not decoded by the TRANET I system receiver, propagation delays from satellites to the receiving antenna are calculated by using the data of Cartesian coordinates of the satellite 30190 which are supplied by the Topographic Center of DMA. Fig. 2 shows an example of propagation delays in vacuum space which were calculated by the precise ephemeris of the satellite 30190.

Receiver delays are measured by transmitting a simulated signal into a space near the receiving antenna at few days interval. During the period before November 28, 1976, the AF type of tracking receiver was used and adjustments of IF circuit were made so as to give a constant delay in the receiver. Thereafter the IF phase-lock tracking receiver was used and only measurements of receiver delay were made without frequent adjustments. Delay time of the IF phase-lock tracking receiver is shown in Fig. 3.

Delays of time signals emitted from satellites can be calculated according to the Lorentz transformation. But classical treatment is sufficient, for the radial velocity of satellites (v) relative to the station fixed on the Earth is very small against the light velocity (c). Then time delay caused by the motion of satellite relative to the tracking station is estimated as

$$(v/c) \cdot (\text{propagation time}) \lesssim 0.5\ \mu s$$

Time delay of this kind is corrected, although this is small.

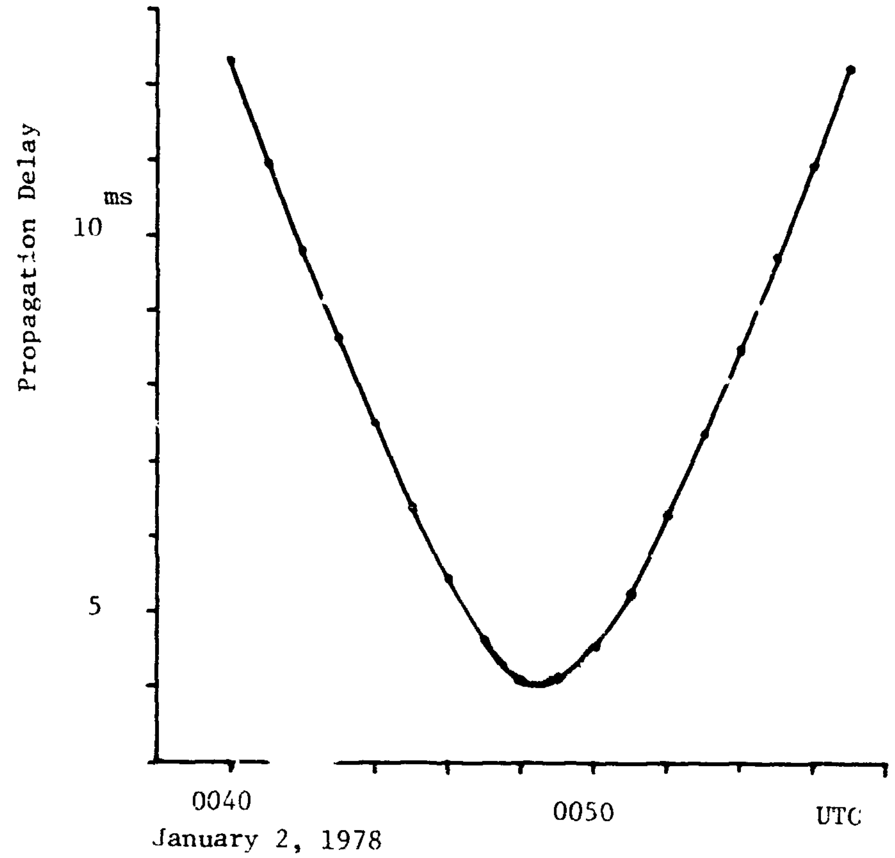

Fig. 2-An example of propagation delays in vacuum space which were calculated from the precise ephemeris of the satellite 30190.

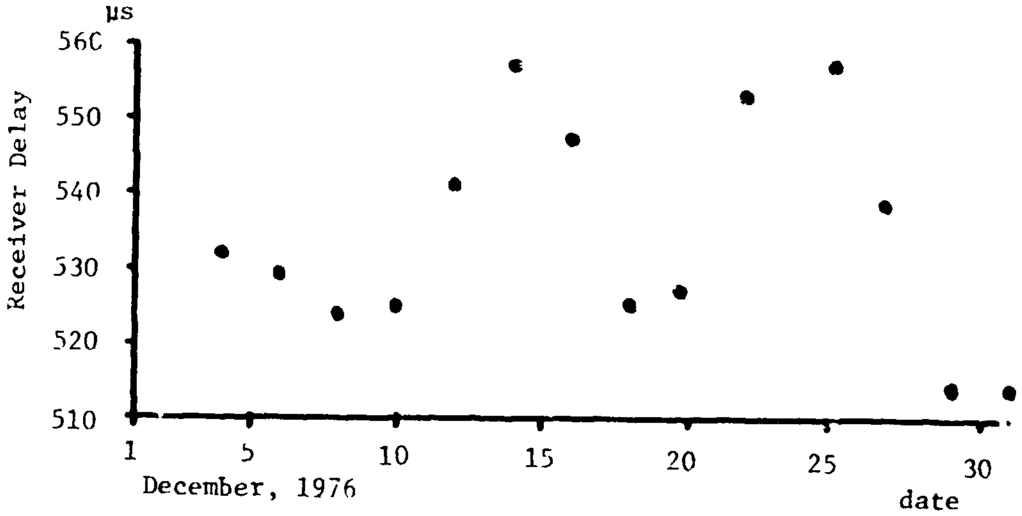

Fig. 3-Receiver delays of the TRANET I IF phase-lock tracking receiver.

## RESULTS

Time differences between the satellite 30190 and the station clock are shown in Fig. 4, where the corrections for propagation delay, receiver delay, and motion of satellite mentioned above are made.

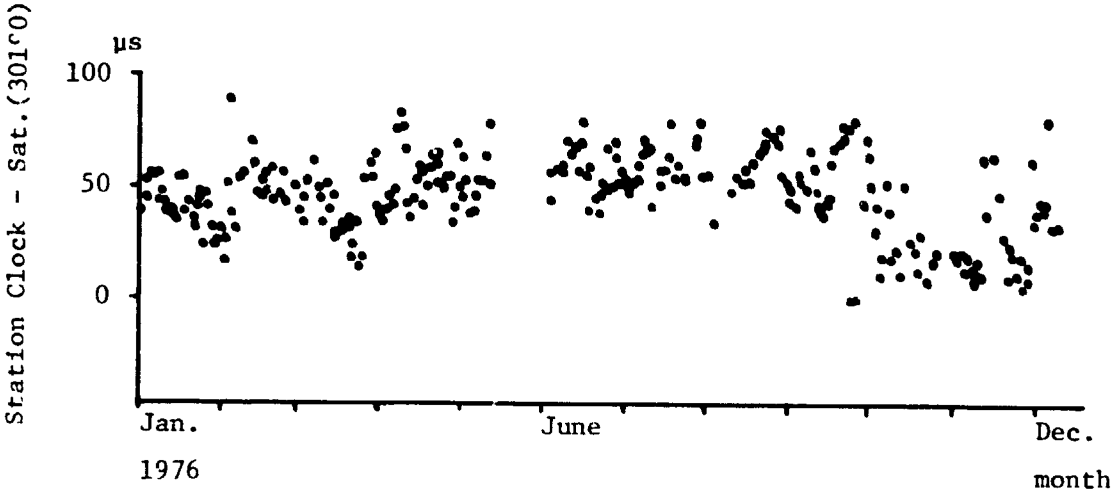

Fig. 4-Emission time of the satellite 30190 observed by the station clock (rubidium atomic clock).

In this calculation, receiver delays are corrected by three constant values in the three periods, respectively, as follows;

| | | | |
|---|---|---|---|
| 775702 μs | before | 23 January | 1976, |
| 775763 μs | until | 28 November | 1976, |
| 775966 μs | after | 28 November | 1976, |

where system delay of 775434 microseconds and 406 Hz circuit delay are included.

The raw data included some extremely deviated values, and these data were rejected by a fixed range filter to pass only the data which were in the range from 0 to 350 microseconds. The refined data were proved to have the standard deviations of ±19 microseconds. The above measurements were made with the station clock of which deviations were about ±1.5 microseconds.

In order to estimate the intrinsic error of the clock comparison via satellite, we tried to remove all the errors of the station clock and satellite-borne clock (see Fig. 5) and receiver delay only for the period after November 28, 1976.

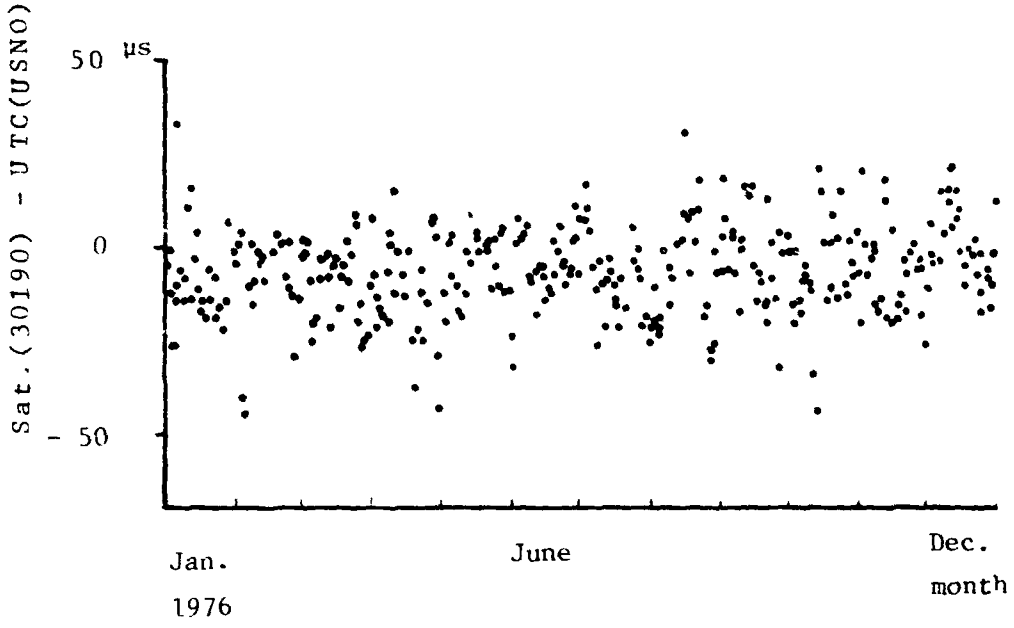

Fig. 5-Time differences between satellite-borne clock (30190) and UTC(USNO). This graph was plotted from the data in Transit Satellite Report, Series 17 which was published by the U.S.Naval Observatory.

The final form of clock comparison was reduced to UTC(ILOM) -UTC(USNO) (see Fig. 6). These two time scales are maintained by the cesium clocks and fluctuations in UTC(ILOM)-UTC(USNO) can be ascribed to timing error aroused by the satellite timing system. Results are summarized below with standard deviations in microseconds;

| | |
|---|---|
| Station Clock - Sat.(30190) | ±19 |
| Sat.(30190) - UTC(USNO) | ±12 |
| UTC(ILOM) - Station Clock | ±1.5 |
| Receiver Delay | ±14 |
| UTC(ILOM) - UTC(USNO) | ±15.5 |

Standard deviations were reduced from ±19µs to ±15.5µs, showing that only slight improvements were attained. This may due to instability of the receiver delay and/or to inappropriate correction of satellite clock.

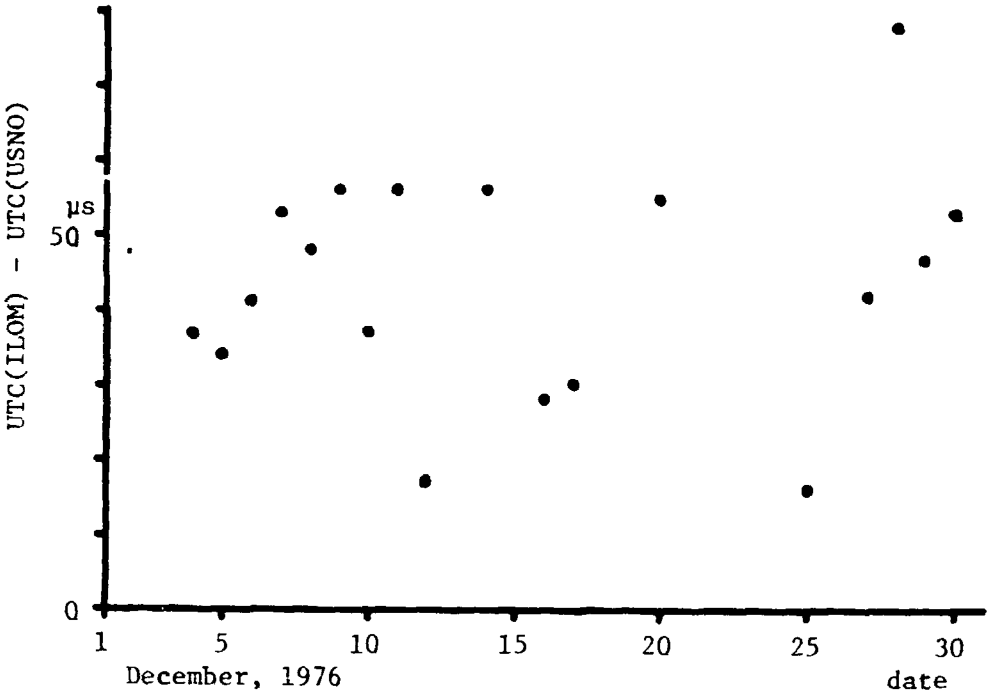

Fig. 6-UTC(ILOM) - UTC(USNO) via Transit satellite 30190.

## TIME SYNCHRONIZATION VIA LORAN-C SIGNAL

The Northwest Pacific Loran-C chain is available in the vicinity of Japan. Most institutes in Japan have been receiving the master station Iwo-jima with the standard deviation of less than ±0.1μs. Receiver delay can be measured with sufficient accuracies, but propagation time seems to be hard to estimate with high accuracies. Propagation time from Iwo-jima to the monitoring station of the chain (Fuchu) was once determined by USNO as 4070.0μs from a calculation combined with a transportation experiment with an atomic clock. RRL when it was in Midori-cho, Koganei-shi, Japan had calculated the propagation time based on above value as 4122.5μs. On the other hand, time synchronization between RRL and ILOM has been made with the aid of a portable clock as well as Loran-C receptions. The difference of propagation times between these two stations and the Iwo-jima station was determined as 1192.4±0.24μs by five clock transportation experiments. Then, propagation time from Iwo-jima to ILOM was obtained as 5314.9μs.

Thus, the quantity of UTC(ILOM) - UTC(USNO) is derived from the Loran-C receptions and the data "Daily Phase Values, Series 4" which is published by USNO (see Fig. 7). By comparing these values with the one obtained by satellite timing signals, it was found that there is a discrepancy of about 35μs.

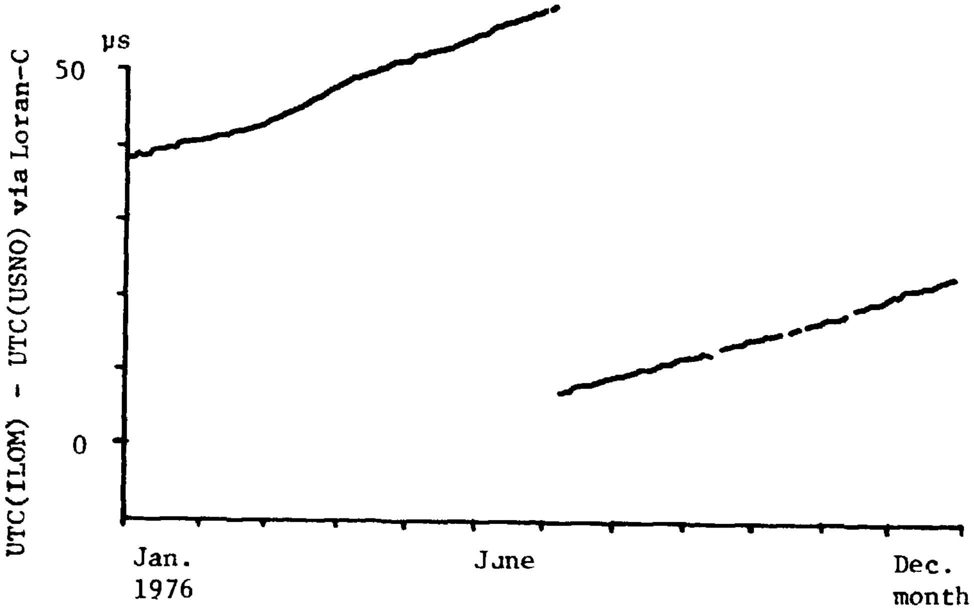

Fig. 7-UTC(ILOM) - UTC(USNO) via Loran-C.

DISCUSSION

The ionospheric effect on radio wave propagation was not corrected in the above results. The order of the effects on propagation delay will be estimated here. As the receiving frequency is 400MHz, geomagnetic field and collision of electrons with neutral gas can well be neglected. Then the optical length ($\tau$) is calculated according to the formula $\tau = \int n ds$, where the integration must be done along the propagation path and n is the refractive index which is in relation with the plasma frequency ($f_p$) and the operating frequency (f) as $n^2 = 1-(f_p/f)^2$. The plasma frequency is related with electron density (N) as $f_p{}^2 = 80.6N$ in MKS unit system. Then the optical length can be estimated from the equation $\tau = \int(1-80.6N/f^2/2)ds$ by using a model ionosphere (Tsuchiya 1976) for the N(h) profile. A numerical calculation was made for the satellite which is on observer's zenith, yielding 0.1μs and 0.05μs in daytime and nighttime respectively. The distance to the satellite which is on the horizon will be four times as large as the one when a satellite is on the zenith. So, maximum propagation delay may amount to 0.4μs and 0.2μs, respectively.

On the other hand, the mean value of station clock - satellite was obtained as 48.95 ±1.39μs and 48.70 ±1.77μs for the daytime and nighttime period, respectively. That is, reception error is above the ionospheric effect, so we can find no significant differences in ionospheric effect between daytime propagation and nighttime one from the above results. Nevertheless we may safely say that the ionospheric effect produces no errors larger than one microsecond when the solar activity is moderate.

At TRANET stations only the data which are obtained when the satellite is near to the closest approach (C.A.) are used for time synchronization purpose. All the data that fall in the range from 0μs to 350μs were used, in our case. Dependency of delay time of timing signals upon the doppler shift of satellite were examined for each datum point in whole passes obtained in 1976 (see Fig. 8).

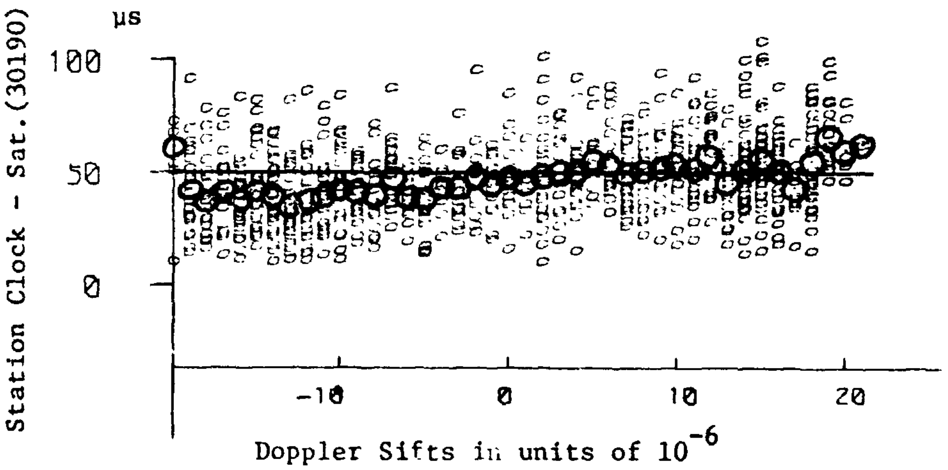

Fig. 8-Station clock - Satellite 30190 which was observed every two minutes. The abscissa is taken as Doppler shift in units of $10^{-6}$. Average value is shown by large circles.

Scattering of data are relatively small near C.A., and furthermore there is a tendency that received signals advance by about 10μs for pre-C.A. period and vice versa for post-C.A. period. This tendency does not differ distinctly whether the reception was made during daytime or nighttime periods. The physical explanation of this tendency is left unsolved even if we take into consideration the tropospheric refraction effects, since these are the order of one microsecond at most.

## CONCLUDING REMARKS

A timing experiment via the Navy Navigation Satellite for the year of 1976 was shown. Our time comparison has shown that fluctuations of the obtained data have the standard deviation of ± 16 μs . This is almost the same order as the reported values by Hunt and Cashion (1978) and Cashion et al. (1978). But there is a discrepancy of 35 μs as compared with the data obtained by the Loran-C reception. There might be some problems in delay time measurement. Furthermore, fluctuations in timing pulses may be pretty large, since the band width of the receiver is narrow.

## ACKNOWLEDGEMENTS

Our thanks are due to Mr.M.Aihara and Dr.I.Okamoto for their discussion and assistance in improving expressions.

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## QUESTIONS AND ANSWERS

MR. LAUREN RUEGER, Johns Hopkins University, Applied Physics Lab:

> Before I open this paper for comments from the audience, I would like to make a couple of comments myself. The first is that the small shift he saw in this last curve is characteristic of what we observed in the tracking loop characteristics of the VCO. He was using a fairly early model Nikode-type receiver that has a fairly simple transfer function for the tracking loop. The lags in that would give him the 10 microseconds I think he is observing.
>
> The second comment is that during 1977, following this data, we did an experiment in making time transfers between the U.S. Naval Observatory and the National Bureau of Standards in which we had very carefully calibrated the receiver delay, to a resolution of 10 nanoseconds. And in using that, we discovered, buried in the data that we now provide through Bulletin 17, a possibility of a 50 microsecond bias because of the uncertainty of the receiver delay.
>
> If you take the 50 microseconds from this source and the 35 microsecond discrepancy this man found, they are in the same direction and compensating. His data is really within his experimental error. We should tell him someday.