Two-Way Satellite Time and Frequency Transfer Experiment via IGSO Satellite

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***Abstract*—In order to study the instability introduced by path non-reciprocity due to satellite motion in an earth fixed frame in Two-Way Satellite Time and Frequency Transfer (TWSTFT), we do TWSTFT experiment between National Time Service Center (NTSC) and Urumchi Observatory (UO) via APSTAR-1 inclined geosynchronous satellite orbit (IGSO) satellite for the first time. The satellite is with the inclination of 2.2 degree and it can moves up to ±1600 km in the direction of perpendicular to equator plane, while SINOSAT-1 geostationary (GEO) satellite moves only up to about 30km in that direction. To improve the quality of observation, the PN-code with chip rate of 20 MChip/s is chosen in SATRE modem in TWSTFT. Each observation period includes 3 hours: APSTAR-1 satellite is observed with the two TWSTFT stations in the first hour, and SINOSAT-1 satellite is observed with the same stations in the second hour, and nothing is done in the third hour. We repeat the periodic observation for about two months in winter in 2006.**

Our analysis is as follows, for a given satellite, we first calculate the ionosphere delay with IGS TEC map data and deduce it from TWSTFT result, for our TWSTFT comparison is with C-band. Then we calculate and deduce Sagnac effect. After that, the variation of difference between the TWSTFT result via SINOSAT-1 satellite and that via APSTAR-1 satellite mainly represents the influence introduced by APSTAR-1 satellite motion in the earth fixed frame. Experiment result and analysis indicate that the path non-reciprocity due to satellite movement in the earth fixed frame in TWSTFT between NTSC and UO via APSTAR-1 satellite varies in an approximate sinusoidal pattern everyday, and the amplitude of the daily variation is about a few tenths of a nanosecond. The experiment is helpful for studying TWSTFT via non-geostationary satellite.

I. INTRODUCTION

Two-way satellite time and frequency transfer (TWSTFT) via geostationary satellites is a particularly useful technique in remote and accurate time and frequency transfer. Primary timing laboratory in Europe, North America and the Asia-Pacific region have established TWSTFT links via geostationary communication satellites for the calculation of International Atomic Time (TAI) and Coordinated Universal Time (UTC). Measurement and stability technique and calibration systems of the delay instabilities have advanced in recent years, and sub nanosecond accuracy may be achieved in TWSTFT[1].

TWSTFT via Geostationary satellites is convenient, for the satellite is almost fixed in earth fixed frame and the small antenna needn't to track. However, the number of satellites existing in geostationary orbit should be considered as finite resources. Non-geostationary satellites, for example, inclined geosynchronous satellite orbit (IGSO), are expected to open up new opportunities for TWSTFT links. Non-geostationary satellite moves rapidly in earth fixed frame, and it may produce non-reciprocal paths in TWSTFT, thus the time transfer accuracy is degraded.

The analysis of influence of satellite motion in TWSTFT was made in NIST, NICT et al. [2,3,4]. At present, APSTAR-1 satellite is an IGSO satellite with the orbit inclination of 2.2 degree. We do TWSTFT experiment between National Time Service Center (NTSC) and Urumchi Observatory (UO) via APSTAR-1 IGSO satellite. Thus we can investigate influence of satellite motion to TWSTFT by practical experiment. To improve the quality of observation, the PN-code with chip rate of 20 MChip/s is chosen in SATRE modem in TWSTFT.

II. SUB SATELLITE PONITS OF APSTAR-1

APSTAR-1 satellite retired in 2004, and it moves to 142 deg. E. In order to economize fuel and prolong its life, the satellite doesn't maneuver in the direction of perpendicular to equator plane and only maneuvers in satellite track direction. At present, the satellite has become an IGSO satellite with the inclination of 2.2 degree. It can moves up to ±1600 km in the direction of perpendicular to equator plane, while SINOSAT-1 geostationary (GEO) satellite moves only up to about 30km in that direction.

Trakstar software implements the NORAD SGP4/SDP4 orbital models for use with the standard two-line orbital element sets to determine earth-centered inertial (ECI) and topocentric coordinates of earth-orbiting objects [5,6]. The

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software implements both the near-earth and deep-space portions of the NORAD SGP4 orbital model. Satellite position and velocity may be calculated with the software and the orbit accuracy may be about 20km.

The longitude and the latitude of APSTAR-1 satellite is calculated with TrakStar software and the two line element (TLE) on December 27,2006, and then its sub-satellite points is shown in Fig. 1.

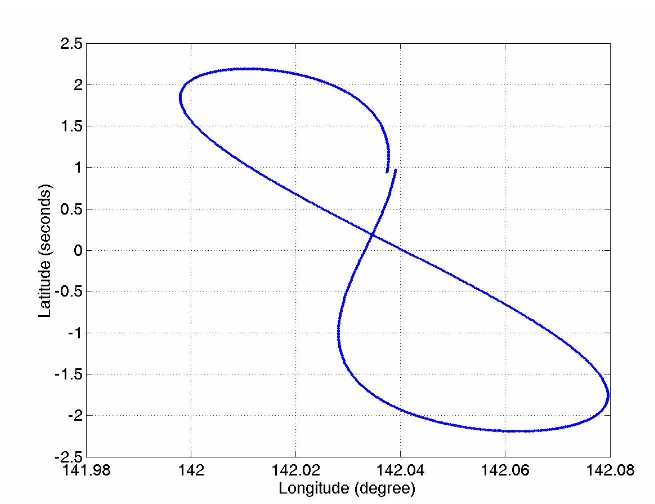

Figure 1. sub-satellite points of APSTAR-1 satellite on December 27,2006

III. Calculation of Satellite Motion and Its' Influence to TWSTFT

Satellite velocity in the direction from Urumchi Observatory (UO) to APSTAR-1 satellite, and that in the direction from National Time Service Center (NTSC) to APSTAR-1 are calculated with TrakStar software and TLE on December 27,2006. the variation of the velocity with time is shown in Fig. 2.

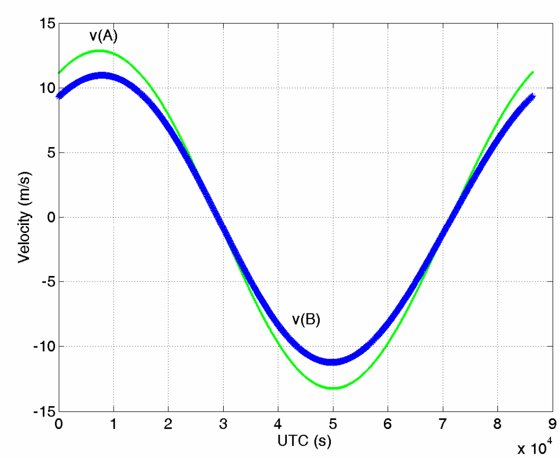

Figure 2. APSTAR-1 satellite velocity from station to satellite on December 27,2006

The variation of the sum of the two velocities is shown in Fig. 3.

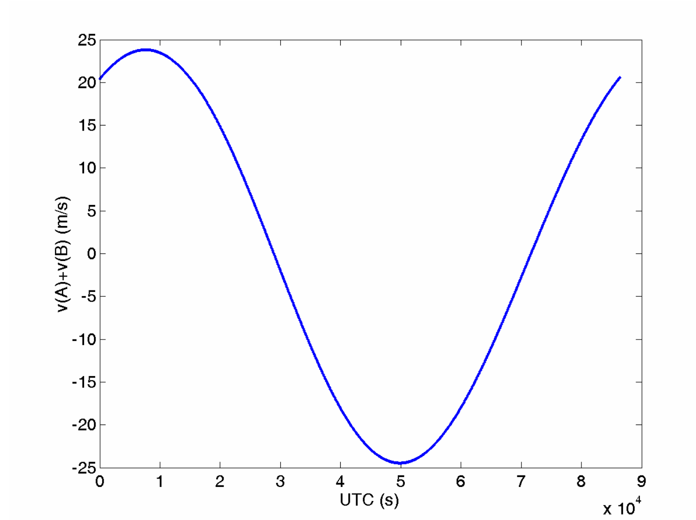

Figure 3. The sum of the two velocities from UO to satellite and that from NTSC to satellite on December 27,2006

Based on TWSTFT principle [7,8], we can calculate the path non-reciprocity due to satellite motion in earth fixed frame. Assuming the two TWSTFT station A and B, the difference between the calculated clock difference and practical clock difference is equal to the path non-reciprocity, which is expressed as

$$\Delta = (d_{AU} - d_{AD})/2 - (d_{BU} - d_{BD})/2$$

$$= \frac{1}{2}(v_{AU} + v_{BU}) \cdot \Delta t \qquad (1)$$

where d_{AU} denotes uplink path of station A's signal, d_{AD} is downlink path of station A's signal, d_{BU} is uplink path of station B's signal, d_{BD} is is downlink path of station B's signal, v_{AU} is satellite velocity from station A to satellite, v_{BU} is satellite velocity from station B to satellite.

From (1), We know that the quantum of path non-reciprocity comes not only satellite motion, but also the difference between the distance from A to satellite and that from B to satellite, and clock difference between two stations. And we know the distance difference and clock difference have the similar influence.

We assume that UO is station A, and NTSC is station B. In our TWSTFT experiment, the clock difference between two stations is about 300ns, and its' influence to path non-reciprocity is very small and may be neglected. The difference between two distances from stations to satellite may be turned to time difference given by

$$\Delta t = \Delta d / c \qquad (2)$$

where Δd denotes the difference between the distance from UO to satellite and that from NTSC to satellite, and it is about 1930km. c is light velocity in vacuum, which is 299792458m/s. The non-reciprocity due to satellite motion is shown in Fig. 4.

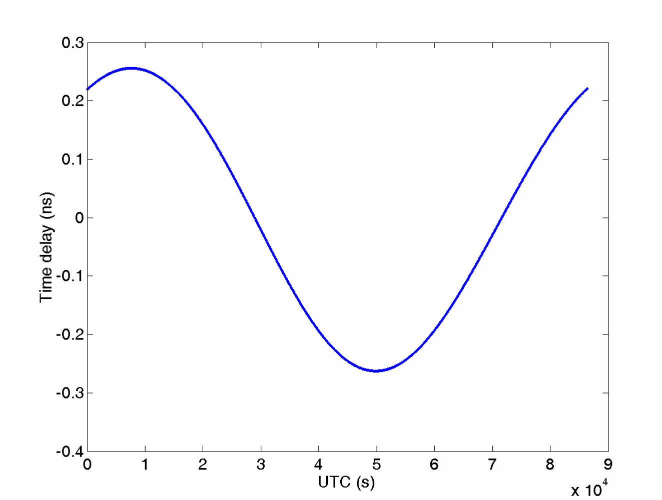

Figure 4. Calculated non-reciprocity path due to APSTAR-1 satellite motion on December 27,2006

From Fig. 4, we know that the non-reciprocity varies in an approximate sinusoidal pattern in one day, and its' amplitude is about 0.25ns.

IV. TWSTFT EXPERIMENT

We do TWSTFT experiment with C band between UO and NTSC in November and December in 2006. Each observation period includes 3 hours: APSTAR-1 satellite is observed with the two TWSTFT stations in the first hour, and SINOSAT-1 satellite is observed with the same stations in the second hour, and nothing is done in the third hour. We repeat the periodic observation for about two months in winter in 2006. To improve the quality of observation, the PN-code with chip rate of 20 MChip/s is chosen in SATRE modem in TWSTFT. There are a HP5071A Cs atomic clock in NTSC and a OSA5585PRS clock in UO.

The same two stations were used in observing IGSO and GEO, therefore, the station equipment delays have the same influence to TWSTFT via GEO satellite and IGSO satellite. In addition, Sagnac effect has also been considered, and we find Sagnac effect varies less than 0.1ns when APSTAR-1 satellite runs in the "8". Ionosphere time delay has also been calculated according to IGS TEC map [9], and its' amplitude is less 0.1ns in November and December in 2006.

There is no maneuver on November 27,2006 and the data is very unique. The data processed result is shown in Fig. 5.

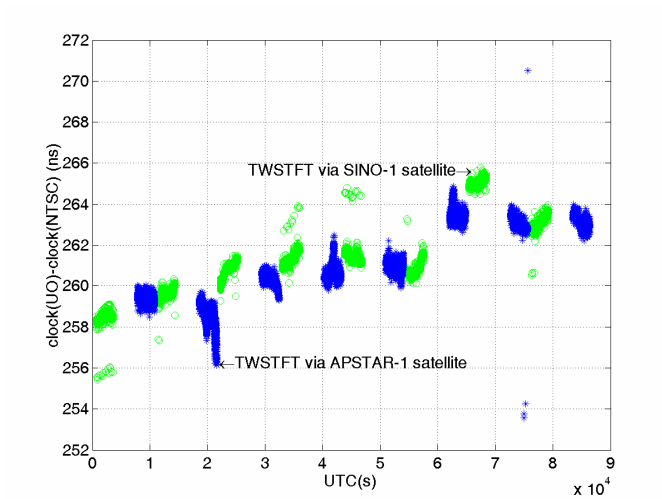

Figure 5. TWSTFT experiment via SINOSAT-1 satellite and via APSTAR-1 on November 29,2006

In Fig.5, the ionosphere time delay has been neglected, and Sagnac effect has been deducted as a constant for APSTAR-1. The Sagnac via APSTAR-1 is 29.8 ns and that via SINOSAT-1 is 56.9 ns.

It's difficult to make out time difference variation from the path non-reciprocity due to satellite motion in TWSTFT via IGSO satellite. In order to amplify the influence from satellite motion, we assume that there is additional 1s clock difference besides the present clock difference, that is, clock (UO) is equal to the sum of clock (NTSC), practical clock difference and additional 1s. Then we process TWSTFT data and the result is shown in Fig. 6.

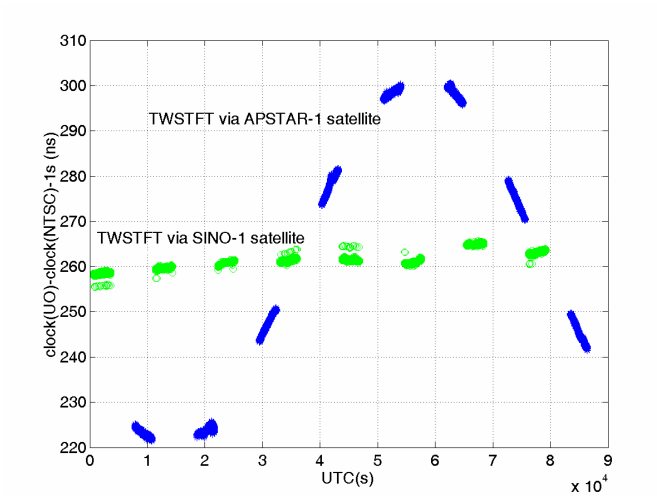

Figure 6. TWSTFT experiment via SINOSAT-1 satellite and via APSTAR-1 on November 29,2006 assuming that there is an additive 1s clock difference between UO and NTSC.

V. ANALYSIS AND DISCUSSION

APSTAR-1 satellite is a now an IGSO satellite with orbit inclination of 2.2 degree. In order to investigate the influence from satellite motion in TWSTFT, the path non-reciprocity due to satellite motion in earth fixed frame has been calculated in TWSTFT via APSTAR-1 satellite between UO and NTSC based on Two Line Element from NASA.

TWSTFT experiment has been down with APSTAR-1 satellite and SINOSAT-1 satellite between the two stations. SINOSAT-1 satellite is a Geostationary satellite, and its TWSTFT result can be looked as reference.

Experiment result and analysis indicate that the path non-reciprocity due to satellite movement in the earth fixed frame in TWSTFT between NTSC and UO via APSTAR-1 satellite varies in an approximate sinusoidal pattern in one day. The variety amplitude of path non-reciprocity is about 0.25ns in one day according to theory analysis. Experiment result shows that the variety amplitude of path non-reciprocity can reach about 41ns if there is 1s clock difference between UO and NTSC. We can also calculate the path non-reciprocity with (1) in such case of 1s offset. The experiment result is identical with the theory calculation result.

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REFERENCES

[1] Bill Klepczynski,"TWSTFT Annual Report 2006", CCTF/06-22, CCTF 2006.

[2] T.E. Parker and V. Zhang , "Sources of Instabilities in Two-Way Satellite Time Transfer",2005 Joint IEEE International Frequency Control Symposium and Precise Time & Time Interval (PTTI) System and Applications Meeting, pp.745-751, 2005.

[3] S Yokota, Y Takahashi, M T Postek and R D Larrabee, "Accuracy of Two-way Satellite Time and Frequency Transfer via Non-geostationary Satellites". Metrologia, vol.42, pp.344-350, 2005.

[4] "The operational use of two-way satellite time and frequency transfer employing PN codes". Rec. ITU-R TF.1153-2, 2003.

[5] TrakStar Version 2.65, http://celestrak.com/software/tskelso-sw.asp.

[6] CelesTrak, http://celestrak.com/.

[7] D.W.Hanson,"Fundamentals of Two-way Time Transfers by Satellite",43rd symposium on frequency control, 1989.

[8] Michito Imae, "Review of Two-Way Satellite Time and Frequency Transfer", Journal of Metrology Society of India,Vol.21, No.4, pp.243-248, 2006.

[9] Yang Xuhai, Li Zhigang, Hua Aihui, "Two-Way Satellite Time Transfer with C Band", to be published in 2007 Joint IEEE International Frequency Control Symposium.