Impact of Satellite Motion on the Asia-Pacific TWSTFT Links

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***Abstract*—Impact of satellite motion on the Asia-Pacific TWSTFT links are analyzed and calculated. Based on the satellite motion, three aspects, which are the different distances from two stations to the satellite, time synchronization error in stations, and the Sagnac effect, result in the non-reciprocal path affecting the TWSTFT accuracy.**

Ⅰ. INTRODUCTION

TWSTFT technique is one of the most prospects in the remote and precise time and frequency transfer. But, it is a relative complicated technique [1]. This is done using a transmitting/receiving earth station in each location, and the two stations simultaneously send a coded signal to the other and receive one via a geo-stationary satellite. Generally, it takes about several minutes to get sufficient data to compute an average or fitting value for diminishing the noise processes.

In addition to some TWSTFT links established in Europe and America, several Asia-Pacific links have being constructed using the communication satellite located 150 deg. E [2], and some time laboratories being involved are the National Institute of Information and Communications Technology of Japan (NICT) that is one of the three international time transfer nodes, the National Metrology Institute of Japan (NMIJ), the National Time Service Center of China (NTSC), the Telecommunication Laboratories of Taiwan (TL), the Korea Research Institute of Standards and Science (KRISS) and the Productivity and Standards Board of Singapore (SPRING).

Currently, the accuracy of the technique is toward as high as 1ns, so the impact of the systematic errors on the accuracy should be studied in detail. An important factor affecting the accuracy is the satellite motion.

Ⅱ. IMPACT OF THE SATELLITE MOTION ON THE TWSTFT LINKS

Since the TWSTFT links use same transponder on the satellite, in very short time (<1ms), the time delay does not almost take place change, thus we think the non-reciprocal path error may be neglected.

The satellite used in TWSTFT is a geo-stationary satellite. Generally speaking, its motion relative the ground mainly includes daily periodical motion and drift motion. To some extend, the distance from the station to the satellite can be considered as a sinusoid with amplitude and period of 24 hours:

$$R = R_0 + R_m \cdot \sin(\frac{2\pi t}{24} + \phi) \tag{1}$$

where R_0 is the normal distance from the station to the satellite, R_m is the amplitude of the daily change, and ϕ is the initial phase. The variation of the distance is:

$$\frac{dR}{dt} = R_m \cdot \cos(\frac{2\pi t}{24} + \phi) \cdot \frac{\pi}{12} \tag{2}$$

Then the greatest rate of variation should be:

$$\frac{dR}{dt} \le R_m \cdot \frac{\pi}{12} \tag{3}$$

where the unit of R_m is km, and that of *dR/dt* is km/h.

According to the various greatest amplitudes, we obtained the greatest velocities relative the ground. Table Ⅰ gives some results.

TABLE Ⅰ
GREATEST VELOCITY OF SATELLITE MOTION

Rm (km)	*dR/dt* (m/s or ns/s)
10	< 0.727 (or 2.424)
20	< 1.454 (or 4.847)
50	< 3.636 (or 12.12)

Based on the satellite motion, three aspects result in the non-reciprocal path.

A. Different distances from stations to the satellite

Since the two distances from two stations to the satellite are different, the time of the two signals from two stations to reach the satellite is different. Thus the satellite receives the two signals at different positions. An extreme case is one station having an elevation of 6 deg. and the other having an elevation of 90 deg.. Thus the greatest difference from the two stations to the satellite is 5893km. Then the corresponding greatest time difference is 19.66ms. If the greatest amplitude reaches 50km, according to the greatest velocity of the satellite motion relative the station, the non-reciprocal error is less than 240ps. Table Ⅱ shows such results of the non-reciprocities in some links that include TL-NICT, KRISS-NICT, SPRING-NICT, and NTSC-NICT.

TABLE Ⅱ
NON-RECIPROCITIES FROM THE DISTANCE DIFFERENTS

Links	Distance differences	Non-reciprocities (greatest amplitude: 50km)
TL-NICT	31km	< 1.3ps
KRISS-NICT	441km	< 17.8ps
SPRING-NICT	745km	< 30ps
NTSC-NICT	1238km	< 50ps

B. Time synchronization error in stations

Since the time at the stations is not synchronous, the time of transmitting signal is not same. However, it is easy to initially synchronize the time of the stations within several tens μs. Thus, the non-reciprocal error from satellite motion should be less than 1ps. Table Ⅲ gives some results of the non-reciprocity

TABLE Ⅲ
NON-RECIPROCITIES FROM TIME SYCHRONIZATION ERRORS IN STATIONS

Synchronization errors	Non-reciprocities (greatest amplitude: 50 km)
20μs	< 0.24ps
50μs	< 0.6ps
80μs	< 0.96ps

C. The Sagnac effect

Due to the Earth' rotation and the finite signal velocity, the non-reciprocal path is produced. The effect on TWSTFT is called Sagnac effect, which can be calculated by following formula [3, 4].

$$E = \frac{2\omega A}{C^2} \qquad (4)$$

where ω is the rate of Earth' rotation, C is the velocity of light, A is the equatorial projection of the area of the quadrangle the vertices of which are the center of the Earth and the positions of the stations on the surface of the Earth, and the position of the satellite with respect to the Earth' surface.

Table Ⅳ gives some results of the effect coefficients of longitude, latitude and altitude of the satellite variation on the non-reciprocities due to the Sagnac effect. It shows that the errors primarily depend on the variation of the satellite longitude and altitude. If there exists such extent of the satellite motion (the longitude is within 150deg.E ± 0.05deg., the latitude is within ± 0.05deg., and the aviation of altitude is within 50km), the error from the Sagnac effect should be more than 100ps in some links.

TABLE Ⅳ
NON-RECIPROCITIES FROM THE SAGNAC EFFECT

Links	Variation from longitude (/0.1deg.)	Variation from latitude (/0.1deg.)	Variation from altitude (/km)
TL-NICT	2ps	0.1ps	1.6ps
KRISS-NICT	23ps	0.05ps	0.8ps
SPRING-NICT	40ps	0.2ps	3ps
NTSC-NICT	66ps	0.13ps	2ps

Ⅲ. CONCLUSIONS

An important factor affecting TWSTFT accuracy is the satellite motion. The errors of three aspects result from the motion. Firstly, since the two distances from two stations to the satellite are different, the non-reciprocities are produced. Secondly, since the time at the stations is not synchronous, the time of transmitting signal is not same, which produces the non-reciprocities. But, to offset the transmission time can weaken the effect. Lastly, for the Sagnac effect, the error mainly results from the aviation of the satellite longitude and altitude, furthermore, due to the error is relative significant, ones should give it more attention.

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