A Simple Digital Satellite TV Timing Method and its Timing Accuracy Analysis

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***Summary*— This study presents a simple and practical digital satellite TV timing method, and identifies the sources of error that affect its timing accuracy. The experimental results demonstrate that the timing accuracy of this method is superior to 100ns.**

Keywords—digital satellite TV timing; satellite timing; timing accuracy

I. Introduction

In 2008, the National Time Service Center(NTSC) of the Chinese Academy of Sciences conducted research on high-precision timing methods for digital satellite TV signals. This research proposed the utilization of Program Clock Reference (PCR) timestamp technology as a means to solve the TV signal transmission delay measurement method [1-3]. In 2015, NTSC proposed the digital satellite TV differential timing method (DSTVDT), which serves as a low-cost, high-precision timing method with an accuracy better than 10ns (rms) and can be widely used in power, communication, and other fields [4, 5].

Building on the foundation of the previous research, this paper introduces a simple digital satellite TV timing method (SDSTVT) that can achieve timing accuracy better than 100ns without the need for precise orbit determination of TV satellites. This method is simpler to use and provides a reliable timing solution for broadcasting, power, communications, and other industries, including large ships. Furthermore, the proposed method can be employed as a backup system for the Global Navigation Satellite System (GNSS), reducing the risk of over-reliance on GNSS.

II. Methods

Suppose a PCR in satellite TV signals is transmitted at UTC time t_O, A and B are two ground stations which receive the PCR in satellite TV signals at local time t_A, t_B, respectively. Then, the clock difference between A, B and UTC are

$$\Delta t_A = t_A - (t_O + \tau_A^{cd}) \tag{1}$$

$$\Delta t_B = t_B - (t_O + \tau_B^{cd}) \tag{2}$$

Where, τ_A^{cd} , τ_B^{cd} are signal transmission delay from TV satellite to A and B, including the geometry delay from satellite to two stations, delay caused by ionosphere, troposphere and Sagnac effect. Clock difference between A and B which derives from subtracting (1) and (2) is

$$\Delta t_{BA} = \Delta t_B - \Delta t_A = t_B - t_A - (\tau_B^{cd} - \tau_A^{cd}) \tag{3}$$

If station A is NTSC, as the base station, then the time of station B can be traced to UTC (NTSC) through (3).

$\tau_B^{cd} - \tau_A^{cd}$ is mainly composed of the geometry delay difference from the TV satellite to the two stations A and B. Meanwhile the SDSTVT only considers the main factors and ignores the influence of other factors on the timing accuracy, that is, in (3),

$$\tau_B^{cd} - \tau_A^{cd} = (R_{OB} - R_{OA}) / c \tag{4}$$

where，R_{OB} and R_{OA} are the distance between the TV satellite and stations A and B, respectively, and c is the speed of light.

III. Discussion

Despite neglecting certain errors, the SDSTVT method can still achieve high timing accuracy. The TV satellite used is a Geosynchronous Earth Orbit (GEO) satellite. Given that stations A and B have fixed positions or known coordinates, the time difference resulting from the Sagnac effect can be corrected. For C-band TV signals, the effects of the ionosphere and troposphere are relatively minor, introducing errors in the order of nanoseconds[4]. The coordinate errors of stations A and B will also increase the timing error. For instance, a coordinate error of 10m for station B will result in a timing error of 0.1m [4].

The impact of ephemeris errors on timing accuracy is proportional to the distance between stations A and B, proportional to the ephemeris error, and inversely proportional to the distance from station A to the satellite. Assuming a TV satellite position error of 10m, a TV satellite orbit height of approximately 36000km, and a distance of 2000km between stations A and B, the resulting timing error due to ephemeris errors is [4, 6]:

$$2000 \times 10 / 36000 \approx 0.56\,\text{m} \tag{5}$$

Through simple calculation, as long as the satellite ephemeris error does not exceed 535m, within 2000km from the base station, the timing error introduced by the ephemeris error does not exceed 100ns.

Based on statistical results of orbital prediction error variations for 753 GEO objects, the average ephemeris error

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of the TV satellite over a 24-hour period using Two Line Element (TLE) parameters is about 460m[7,8]. The timing error introduced by this ephemeris error is approximately 25.6m or 86ns. Thus, when users employ SDSTVT for time synchronization, the quality requirements for input parameters are quite low, including coarse base station and user positions (with a precision of ten meters), PCR timestamps generated by the same TV program, and ephemeris data with an orbital error less than 535m (such as ephemeris predicted by TLE).

On September 27-28, 2022, SDSTVT was tested at NTSC (Xi'an) and Sanya, which are approximately 1800km apart. Xi'an served as the base station, while Sanya was the user. Zhongxing 6B (with a substellar point of 115°E) and Jiangsu Satellite TV were used for TV satellites and programs, respectively. The satellite ephemeris employed was predicted by TLE within 24 hours. Sanya station synchronized its local time to Xi'an station using the system for remotely reproducing UTC(NTSC) with high precision (time synchronization deviation ±2 ns [9]) as the reference time. The clock difference error ΔT between Sanya and Xi'an, as determined by SDSTVT, is shown in Fig.1.

As evident from Fig.1, the 48-hour test results demonstrate that the timing error rms of SDSTVT is 45.8ns, which is less than the 86ns introduced by the ephemeris error. These results confirm the effectiveness of the SDSTVT method and validate the timing accuracy analysis results presented in this paper.

IV. Conclusions

SDSTVT is a straightforward and easily deployable method for satellite timing. It corrects only significant sources of error and disregards smaller error sources, simplifying the calculation process. SDSTVT has low accuracy requirements for satellite ephemeris. It can ensure timing accuracy of 100ns when ephemeris error is less than 535m. Since digital satellite TV signals have extensive coverage, SDSTVT can provide a rapid and effective timing method when GNSS signals are blocked or interfered. Furthermore, if the user receives TV signals from multiple satellites, effective data fusion can further improve timing accuracy.

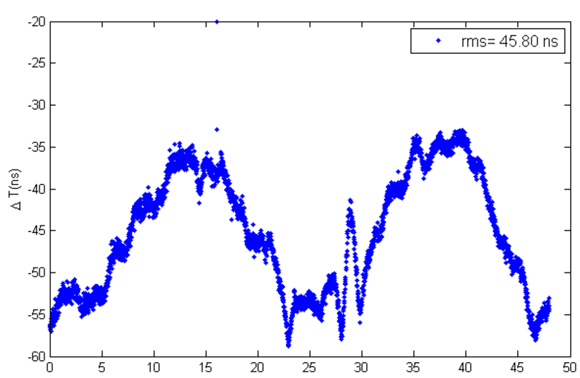

Fig. 1. Clock difference error of SDSTVT

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