Precise Common-View Time and Frequency Transfer (PCVTFT) based on BDS GEO satellites

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1 Problem and its solution: PCVTFT

GPS time transfer with code and Two-Way Satellite Time and Frequency Transfer (TWSTFT) are the main techniques for generating UTC in recent years in BIPM .

Common-view time transfer with carrier phase observation has been studied since several years ago. However, the ambiguity problem is still not well solved.

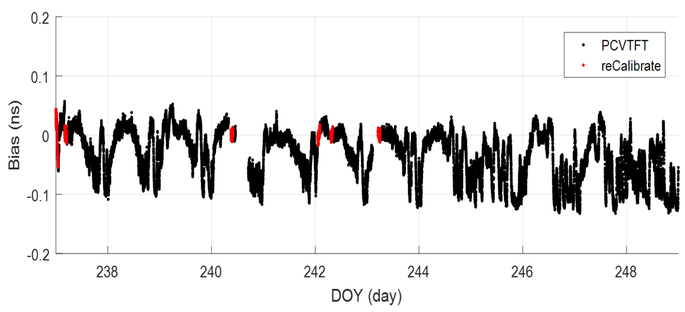
BDS has 5 GEO satellites. Based on the characteristic, method of Precise Common-View Time and Frequency Transfer (PCVTFT) based on BDS GEO satellite is presented. PCVTFT improves the traditional GPS CV time transfer, it uses BDS GEO satellite and carrier phase observation, and use the iGMAS or IGS orbit products, to get high accuracy.

The main advantage of PCVTFT is that two stations can see the GEO satellite all the time, so there is only one ambiguity in very long time (e.g. one year). In contrast, there are usually two ambiguities each day for each MEO satellites.

Frequency transfer is not influenced by ambiguity, but is more convenient with GEO satellite.

2 Zero-baseline experiment

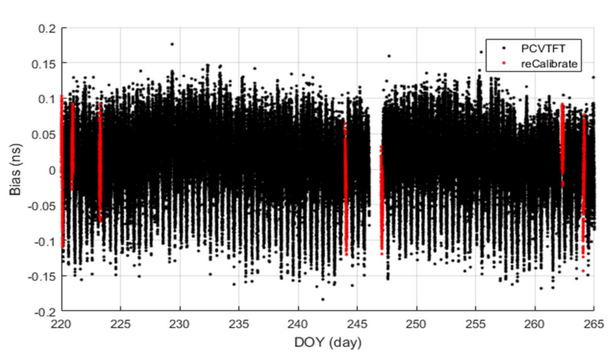
- Both receivers are SEPT POLARX4TR , they are connected to signal of UTC(NTSC), the master clock is an active hydrogen maser, two receivers are with one common antenna.
- The sampling interval is 30s.
- Observation period: Aug 25, 2018 (DOY 237) to Sep 6, 2018 (DOY 249).
- The mean value of the first 3 hours data after each interruption is used as calibration.



We only process the carrier phase of BDS G3 satellite(110.5° E) . The clock difference is calculated by PCVTFT. The **red dot** is calibrated data based on zero. The RMS value of the data is 0.041ns .

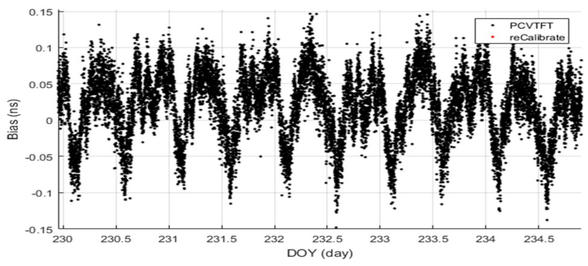
3 Ultra-short baseline experiment

- The data of two receivers (pt09 and pt11) placed in PTB is used in this experiment. Two receivers are with different antenna, the baseline is about 300 m.
- Both receivers are SEPT POLARX4TR , they are connected to signal of UTC(PTB).
- The sampling interval is 30s.
- Observation period: Aug 8, 2018 (DOY 220) to Sep 22, 2018 (DOY 265).



- The mean value of the first 3 hours data after each interruption is used as calibration.

We only process the carrier phase data of BDS G5 satellite (58.75°E) . The clock difference is calculated by PCVTFT. The **red dot** is calibrated data based on zero. The RMS value of the data is 0.046ns .



From the partial figure of pt09-pt11 ultra-short baseline experiment above and the figure of zero baseline experiment, diurnal variations can be noticed. It is assumed to be caused by the temperature variation.

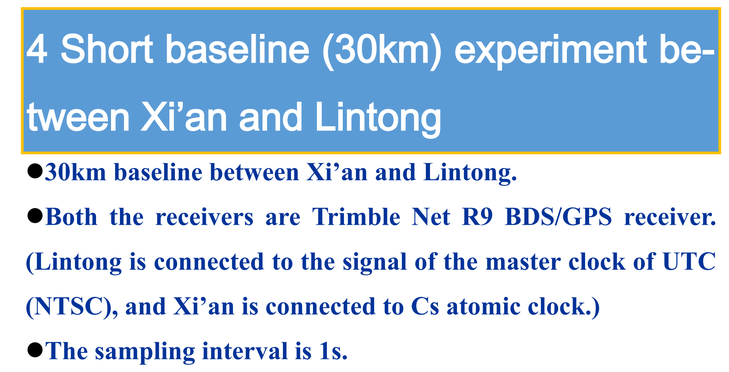
4 Short baseline (30km) experiment between Xi'an and Lintong

- 30km baseline between Xi'an and Lintong.
- Both the receivers are Trimble Net R9 BDS/GPS receiver. (Lintong is connected to the signal of the master clock of UTC (NTSC), and Xi'an is connected to Cs atomic clock.)
- The sampling interval is 1s.
- Observation period: Jan 5, 2016 (DOY 5) to Jan 13, 2016 (DOY 13).

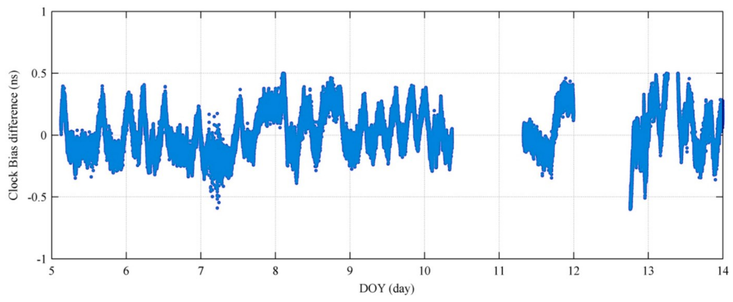
Two Way Optical Fiber Time and Frequency Transfer (TWOTFT) is also carried on at the same time, for comparing and verifying PCVTFT.

Fiber is directly connected from Xi'an to Lintong, and there is no router.

TWOTFT has better accuracy and stability for the symmetry link and avoiding many influence in space when the baseline is short.



The clock difference (Xi'an - Lintong) from PCVTFT, and that from TWOTFT, are in one figure. We only process the carrier phase of BDS G3 satellite (110.5°E) . **Blue one** is PCVTFT result, **black one** is TWOTFT result, and they are basically the same.

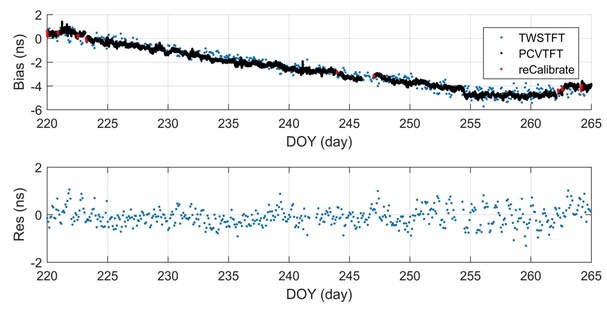


The difference between PCVTFT result and TWOTFT result, the RMS value is better than 0.2ns.

5 Long baseline (700km) experiment between OP and PTB

- Baseline between OP(op71) and PTB(pt09) is about 692km.
- Both the receivers are SEPT POLARX4TR BDS/GPS receiver, op71 is connected to UTC(OP), and pt09 is connected to UTC(PTB).
- The sampling period is 30s.
- Observation period: Aug 8, 2018 (DOY 220) to Sep 22, 2018 (DOY 265).

TWSTFT result published by BIPM is also carried on at the same time, it is used to compare and verify **PCVTFT**, and it uses the GEO communication satellite.

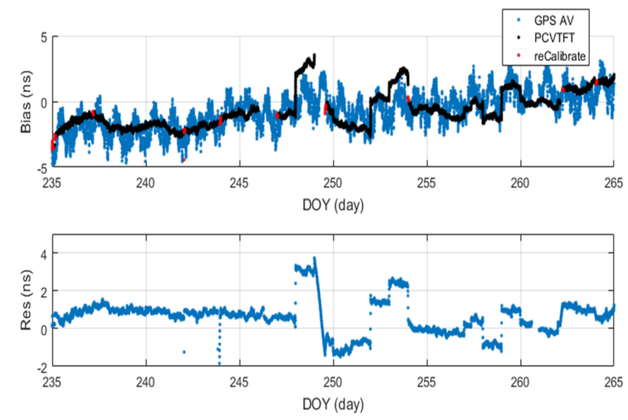


We only process the carrier phase data BDS G5 satellite(58.75°E) . After each interruption, PCVTFT is **calibrated** using the first 3 hours TWSTFT result. The residuals respect to TWSTFT is also showed in the figure, the RMS value is 0.36ns.

6 Very long baseline (7000km) experiment between NTSC and PTB

- Baseline between NTSC and PTB(pt09) is about 7171km.
- Both the receivers are SEPT POLARX4TR BDS/GPS receiver, The receiver of NTSC is connected to the signal of the master clock of UTC(NTSC), and pt09 is connected to UTC(PTB).
- The sampling period is 30s.
- Observation period: Aug 23, 2018 (DOY 235) to Sep 22, 2018 (DOY 265).

GPS All in View (AV) result published by BIPM is used to comparing and verifying **PCVTFT**.



We only process the carrier phase data BDS G5 satellite(58.75°E) . After each interruption, PCVTFT is **calibrated** using the first 3 hours GPS AV result. The daily boundary showed in the figure is caused by the mismatch of precise orbit between days. PCVTFT can not be used on such a long baseline until the accuracy of the orbit of BDS GEO satellites is improved.

7 Summary

1) In zero-baseline and Ultra-short baseline, the Allan variance of PCVTFT is better than $1.96*10^{-14}$, (τ=$1.3*10^5$s, about 1 day). And the RMS value is better than 0.05ns.
2) In short-baseline (30km), the Allan variance of PCVTFT is $2.06*10^{-14}$, (τ=$1.3*10^5$, about 1 day),) . And the difference between PCVTFT and TWOTFT (fiber) is less than 0.2ns.
3) In long-baseline (700km), PCVTFT and TWSTFT are identical, the RMS value of the residuals is less than 0.5ns.
4) In very long-baseline (7000km), there is a daily boundary issue cause by orbit product in PCVTFT.

In general, PCVTFT use the BDS characteristic--- GEO satellite, two stations can see the GEO all the time, so there is only one ambiguity in very long time (e.g. 1 year). PCVTFT can get high precision and accuracy.

In addition, it's a independent technique for only using the iGMAS or IGS product, so it is easy to be applied in time science field.

8 Future work

1) Use a relay station to achieve a very long baseline PCVTFT experiment.
2) The first ambiguity should be solved with other technique.
3) How to combine multiple frequency and GEO satellites? (at least , the influence of maneuver should be solved)
4) The relative receiver delay should be measured in order to get high accuracy in time transfer.