TIMING ACCURACY OF LF AND TV SYNCHRONIZATION TECHNIQUES

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ABSTRACT

LF and TV synchronization techniques have been widely used in China for several years. Shaanxi, Shanghai and Beijing Astronomical Observatories have cooperated with the U. S. Naval Observatory in making two portable clock calibration experiments in 1981 and 1982. The results indicate that the LF synchronization method can reach a timing accuracy of $\pm 1$ µs and a precision of $\pm 0.05$ µs to $\pm 0.20$ µs over a range of 2000km with complex mixed paths. In addition, it has been found that there is a systematic difference of about 4 µs between USNO and other laboratories via the North-West Pacific Loran-C chain. The experiment also shows that the timing accuracy for the passive TV synchronization method is about $\pm 1$ µs and the precision of daily frequency calibrations is better than 2 parts in 10 to the 12th.

## I. INTRODUCTION

Precise time and frequency comparison among Shaanxi, Shanghai and Beijing Astronomical Observatories has been accomplished via different techniques. Since 1974, Loran-C has been used in China for the determination of the accuracy and the long-term stability of many types of atomic frequency standards. In 1978, an experimental LF pulse-coded transmitter station (BPL), which is controlled by Shaanxi Astronomical Observatory, was put into service for precise time and frequency in China. The equivalent values of conductivity over land in China for the LF signal were measured, and the signal strength and the time delay of the ground wave at 100kHz were predicted for most of the timing centers. Now, the LF pulse-coded sync technique has been widely used for time and frequency in China.

Time and frequency comparisons via television signals have been used on a daily basis for more than seven years between these observatories. This is a very simple and valuable method. Time delays between Beijing and other cities, such as Xian, Shanghai, etc., through microwave relay routing of the Chinese Television Network have been measured. Passive TV Line-6 comparison is used not only for frequency calibration but also for time distribution.

[1] This cooperative program also includes the following people:
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The portable clock is still the best technique available for the remote synchronization of clocks because it is independent of propagation errors. Shaanxi, Beijing and Shanghai Observatories cooperated with the U. S. Naval Observatory in making two portable clock experiments in 1981 and 1982 in order to evaluate the timing accuracy and precision of the LF and TV techniques.

## II. RESULTS AND ANALYSIS FOR LF SYNCHRONIZATION TECHNIQUE

The results of the comparison between the portable clock, received Loran-C signals, and local master clocks in different labs are given in Tables 1 and 2, separately. It is obvious that precisions for Loran-C reception (sample time = 1 hour) at SO, CSAO and BAO are 0.046, 0.178 and 0.089 $\mu$s, respectively.

Table 1. Time difference (in $\mu$s) between portable clock and local Loran-C received (PC-LCr) in August 1982

| | | PC-LCr(SO) | | PC-LCr(CSAO) | | PC-LCr(BAO) |
|---|---|---|---|---|---|---|
| Period | Aug | $19^d15^h$-$20^d15^h$ | Aug | $21^d10^h$-$22^d10^h$ | Aug | $25^d14^h$-$26^d14^h$ |
| Mean | | 62286.023 | | 66224.050 | | 65706.870 |
| rms | | $\pm 0.046$ | | $\pm 0.178$ | | $\pm 0.089$ |

* Abbreviations used here are:

CSAO Shaanxi Observatory
SO Shanghai Observatory
BAO Beijing Observatory

PC Portable Clock
LCr Loran-C Received

Table 2. Results (in $\mu$s) of comparison between portable clock and local master clock in August 1982

| | | MC(SO)-PC | | MC(CSAO)-PC | | MC(BAO)-PC |
|---|---|---|---|---|---|---|
| Period | Aug | $19^d15^h$-$21^d01^h$ | Aug | $21^d10^h$-$25^d05^h$ | Aug | $25^d14^h$-$26^d21^h$ |
| Frequency offset | | $-7.0\times10^{-13}$ | | $-4.7\times10^{-13}$ | | $-3.1\times10^{-13}$ |
| stability ($\tau$= 3 hour) | | $\pm 6.0\times10^{-13}$ | | $\pm 5.5\times10^{-13}$ | | $\pm 6.1\times10^{-13}$ |

The accuracy of Loran-C timing mainly depends upon a knowledge of the distance, the earth conductivity and the refractive index of the air between transmitting and receiving sites. It also depends upon the measurement of the delay of the receiving system. The time difference between the portable clock and the received Loran-C signal from Table 1 is

$$
\begin{aligned}
(PC\text{-}LCr)_t = \; & (UTC(USNO,MC)\text{-}LCe)t \\
& -(UTC(USNO,MC)\text{-}PC)_{to} \\
& +\Delta PC(t\text{-}to) \\
& +(LCe\text{-}LCr),
\end{aligned}
$$

| | |
|---|---|
| where (UTC(USNO,MC)-LC) | is the time signal correction at some moment, t, that comes from USNO publication, Series 4, |
| (UTC(USNO,MC)-PC) | is the time difference of the portable clock with respect to the Master Clock (USNO), |
| $\Delta$PC(t-to) | is the rate correction of the portable clock during the period (t - to) |
| LCe-LCr | is the total delay between the transmitting and receiving sites, which includes emission delay, propagation delay, receiving delay and the cycle correction. The results of the calculations are summarized in Table 3 (Ref. 1). |

The results of calculations and the calibration experiment with portable clocks are compared in Table 4. Sync errors for each pair of observatories are summarized in Table 5. Although these observatories have different distances from the transmitter stations, different paths and receiving conditions, the average sync error for two labs, as derived from the data from Table 4, is 0.57 $\pm$0.27 μs.

Table 3. Measured time delays (in μs) of the Y slave station of the Northwest Pacific Loran-C Chain (GRP=99700 μs) as determined at three observatories.

| | SO | CSAO | BAO |
|---|---|---|---|
| Distance | 828.840 km | 2006.232 km | 1853.607 km |
| Emission delay | 59463.18 | 59463.18 | 59463.18 |
| Cycle correction | 30.00 | 30.00 | 30.00 |
| Receiving delay | 25.9 | 28.9 | 25.3 |
| Propagation delay | 2767.39 | 6702.67 | 6189.74 |
| Total Delay | 62286.47 | 66224.75 | 65708.22 |

Table 4. Results of experiment and calculation for the Loran-C sync (unit = $\mu s$)

| | Shanghai | | Shaanxi | | Beijing | |
|---|---|---|---|---|---|---|
| | 1981 | 1982 | 1981 | 1982 | 1981 | 1982 |
| UTC(MC)-LCe | 2.6 | 3.6 | 2.6 | 3.6 | 2.6 | 3.6 |
| -(UTC(MC)-PC) | -0.95 | -0.4 | -0.95- | 0.4 | -0.95 | -0.4 |
| LCe-LCr | 62286.47 | 62286.47 | 66222.20 | 66224.75 | 65708.22 | 65708.22 |
| (PC-LCr)cal | 62288.12 | 62289.67 | 66223.85 | 66227.95 | 65709.97 | 65711.42 |
| (PC-LCr)meas | 62283.81 | 62286.02 | 66219.00 | 66224.05 | 65704.85 | 65706.87 |
| Meas. - Cal. (PC-LCr) | -4.31 | -3.65 | -4.85 | -3.90 | -5.12 | -4.55 |

Table 5. Sync error between two observatories via LC/9970

| | CSAO-SO | BAO-CSAO | SO-BAO |
|---|---|---|---|
| 1981 | -0.54 | -0.27 | -0.81 |
| 1982 | -0.25 | -0.65 | -0.90 |

Note also from Table 5 that the annual change in the sync error between SO and BAO is very small, less than 0.1 $\mu s$. This means that the Loran-C time signal in different years and different months is rather stable. A conservative estimation is that it is stable to better than 0.5 $\mu s$. Even for the CSAO, which changed receivers and their location, the variation of the sync error is only 0.95 $\mu s$. It is clear that a timing accuracy at the level of 1 $\mu s$ within the range of 2000 km over complex mixed paths via LF can be reached.

It is worthwhile to notice that the average difference between measurement and calculation in Table 4 is

$$-4.39 \pm 0.56\ \mu s,$$

which, in fact, implies that there is a common systematic error between the USNO and each of the three observatories. In Japan there is a similar result. For example, Tokyo Astronomical Observatory (TAO), in October 18, 1982, measured UTC(TAO)-PC = 6.5 $\mu s$. From TAO publications, one can deduce that the time difference of the Loran-C time signal relative to UTC(TAO) is UTC(TAO)-LCe = 5.4 $\mu s$. Thus from measurement, we have PC-LCe = -0.9 $\mu s$. On the other hand, the time difference between the portable clock and the Loran-C signal at the emission station, calculated from USNO publication Series 4, is

$$\text{PC-LCe} = (\text{UTC(USNO,MC)-LCe}) - (\text{UTC(USNO,MC)-PC}) = 3.25\ \mu s.$$

It is evident that the difference between measurement and calculation for the USNO relative to TAO is -4.15 μs. This systematic error is consistent not only with the results from Shaanxi, Shanghai and Beijing Observatories, but also with the historical results from TAO (Ref. 2). The reason for this error should be investigated further.

In addition, one can see from the results in Table 4 that the average difference between measurement and calculation in 1981 is -4.39 μs, but in 1982 is -3.43 μs. The difference of about 1 μs reflects the precision of the correction values in Series 4 published by the USNO.

## III. RESULTS AND ANALYSIS FOR TV SYNC TECHNIQUE

Beijing, Shaanxi and Shanghai observatories have developed a TV Line-6 system (line 6 pulse of the odd field in the 625 line system) as a method of comparing remotely located clocks in China. The results of TV comparison during the period of portable clock calibration experiment in October, 1982 are listed in Table 6. According to the measurement of time delay for the microwave relay network and calculation of the propagation delay between the local TV transmitter and the receiver (Ref. 3), we can get the time delays between the Beijing Microwave Master Station (BMMS) and each lab as follows:

Time delay of (BMMS-CSAO) = 3611.0 μs,
Time delay of (BMMS-SO) = 6835.1 μs,
Time delay of (BMMS-BAO) = 75.3 μs.

Using the above data during the period of portable clock trip, the measurement error of single time difference from day to day for TV method is as follows:

±0.027 μs for (CSAO-BAO),
±0.061 μs for (SO-BAO),
±0.025 μs for (SO-CSAO).

The relative frequency offsets measured by the portable clock and the TV Line-6 technique are summarized in Table 7.

Table 6. Time differences between the CCTV signal and the local master clocks during the October 1982 clock trip in μs

| | MC(BAO)-TV | MC(CSAO)-TV | MC(SO)-TV |
|---|---|---|---|
| October 19 | 17216.35 | 20748.86 | 3947.94 |
| 20 | 38794.79 | 2326.94 | 5558.07 |
| 21 | 12518.86 | 16051.27 | 39250.49 |
| 22 | 4023.83 | 7556.28 | 30755.62 |
| 23 | 920.34 | 4452.63 | --- |
| 24 | 28677.47 | 32209.80 | --- |
| 25 | 32663.43 | 36195.74 | --- |

Table 7. Relative frequency offset between local master clocks measured by different techniques

| | CSAO-BAO | SO-BAO | SO-CSAO |
|---|---|---|---|
| TV | $-3.6\times10^{-13}$ | $7.5\times10^{-13}$ | $10.1\times10^{-13}$ |
| PC | $-1.6\times10^{-13}$ | $-3.9\times10^{-13}$ | $-2.3\times10^{-13}$ |
| $\Delta$PC-TV | $-2.0\times10^{-13}$ | $11.4\times10^{-13}$ | $12.4\times10^{-13}$ |

It is obvious that the precision of frequency comparisons via TV is:

$2\times10^{-13}$/day for CSAO - BAO,
and $2\times10^{-12}$/day for SO - CSAO and SO - BAO.

The results of time comparisons by use of portable clocks and passive TV techniques are given in Tables 8 and 9. It shows that the sync error between CSAO and BAO is -0.78 $\mu$s; the error for CSAO and SO is -1.82 $\mu$s; and the average timing accuracy is $1.3\pm0.74$ $\mu$s.

Table 8. Comparison between time differences (SO-CSAO) measured by the portable clock and the TV sync on October 20, 1982 ($\mu$s)

| | SO | CSAO | SO-CSAO |
|---|---|---|---|
| MC-TVr | 5558.07 | 2326.94 | |
| TVe-TVr | 6835.1 | 3611.0 | |
| MC-TVe | -1277.03 | -1284.06 | 7.03 |
| MC-PC | 8.694 | -0.153 | 8.85 |

Note: The time difference value of (MC(CSAO)-PC) on October 20, 1982 is obtained by extrapolating the values of October 21 and 22.

Table 9. Comparison between time difference (CSAO-BAO) measured by the portable clock and the TV sync on October 25, 1982 ($\mu$s)

| | CSAO | BAO | CSAO-BAO |
|---|---|---|---|
| MC-TVr | 36195.74 | 32663.43 | |
| TVe-TVr | 3611.0 | 75.3 | |
| MC-TVe | 32584.74 | 32588.13 | -3.39 |
| MC-PC | -0.392 | 2.22 | -2.61 |

Note: The time difference value of (MC(CSAO)-PC) on October 25, 1982 is obtained by extrapolating the values of October 23 and 24.

## IV. CONCLUSION

LF and TV sync techniques provide an excellent medium for the dissemination of precise time and frequency on a continuous basis. The portable clock is an absolute technique with a precision of about 0.1 $\mu s$. The results of the portable clock experiment indicate that LF sync technique can reach a timing accuracy of $\pm 1 \mu s$ and precision of $\pm 0.05$ - $\pm 0.2 \mu s$ within a range of 2000 km of the groundwave coverage. In addition, it has been found that there is a systematic error of about 4 $\mu s$ between the USNO and other labs via the Northwest Pacific Loran-C Chain. For passive TV sync, the timing accuracy is about 1 $\mu s$, and precision of the daily frequency calibration is better than $2 \times 10^{-12}$.

## REFERENCE


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## QUESTIONS AND ANSWERS

A VOICE:

Why was the four microseconds there? Do you know?

MR PAN:

We think the problem is that it is an adopted value, because we checked the receiving delay and we checked the propagation delay; and we think that for the propagation delay, we get better than one microsecond because - you see in Table 5 we listed the time difference between the different observatories in China, and we can see the difference is less than one microsecond. But, as you know, since the observatories are far away from the North-west Pacific Ocean Loran-'chain', because the distance is from 800 kilometers to 2000 kilometers, and today you have a different path, completely different. So we thought we could predict the propagation delay to better than one microsecond.

DR. WINKLER:

I would like to make a comment. About the origin of the four microseconds is clearly an adopted value for the propagation delays in some original monitor stations; but there is one thing to consider, at that time, loop antennas were used. Today, many people use whip antennas. If you use a loop antenna, there are many loops in existence which have the arrow pointing in the wrong direction. If you use one of these you have an error of five microseconds. This is a fact of life.

So, therefore, my suspicion is that somewhere in our original calibrations there must have been a loop confusion. We actually deal with a discrepancy between the computed delay and the measured delay of slightly larger than one microsecond.

Of course, we have no choice but to stick to the value which we have adopted. You cannot jump around between adopted values.