Disciplined Oscillator System by UTC(NIM) for Remote Time and Frequency Traceability

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***Abstract*—Using GNSS time and frequency transfer receiver NIMTFGNSS-1, RTRC by GNSS code based time and frequency transfer has been realized. As the extension of RTRC, NIM can provide one low-cost Rubidium oscillator disciplined by UTC(NIM) in near real-time, NIMDO. Its performances have been verified and demonstrated at the two campuses of NIM. Referenced to UTC(NIM), we can acquired that the time and frequency accuracy of NIMDO could separately be better than 5 ns and 1e-13 averaging one day, and the time and frequency stability averaging one day could respectively be better than 5 ns and 6e-14.**

Keywords—*disciplined oscillator; time and frequency; GNSS; traceability*

I. Introduction

The purpose of RTRC(Real Time Remote Calibration) (see some details in [1]) is to make an easy and fast way for the clients to calibrate their time and frequency standards by being compared to UTC(NIM) (National Time and Frequency Primary Standard of China) in near real time. The results of comparison between UTC(NIM) and the standards can be checked at a website which was built to show near real-time and historical comparison results more intuitively.

The time and frequency standard plays a very important role in metrology. Based on the NIMTFGNSS-1 (see some details in [2]), one low-cost Rubidium oscillator disciplined by UTC(NIM) in near real-time, NIMDO(UTC(NIM) Disciplined Oscillator), which is an important part of RTRC system has been build at NIM(National Institute Metrology, China) and in operation.

The NISTDO (UTC(NIST) Disciplined Oscillator) has been implemented and has good performance in accuracy and stability of time and frequency (see some details in [3]). However, we should have the time and frequency standard directly traced to UTC(NIM), for the completion of the civil time tracing hierarchy. NIMDO has the instant and direct traceability to UTC(NIM) when powered on and in stable running and might be fit for the user who needs the time scale or frequency standard which time or frequency should be traced to UTC(Temps Universel Coordonné) legally. NIMDO can exempt the clients operating ceaseless some kind atomic clock from periodically calibrating it referenced to UTC, which leads to much consuming of manpower, material resources and time.

II. Design and Implementation

NIMDO is the significant extension of RTRC that is described in Fig. 1. If we acquire the GNSS(Global Navigation Satellite System) Common-View(CV) data from the reference station through some kind of near real-time communication method and those from the local station, we can steer the disciplinable oscillator to the reference, such as UTC(NIM), by time and frequency differences derived from the GNSS CV results between two stations. So there should be GNSS time and frequency transfer system which is the most important part and used for the measurements of the time and frequency transfer data, the disciplinable oscillator which can be steered and is used to provide frequency with 10MHz and 1PPS(Pulse Per Second) signals, the steering algorithm and one industry computer as the controller in NIMDO. Thus the scheme of NIMDO could be illustrated as follows in Fig. 2.

Our implementation of NIMDO is photographed in Fig. 3. According to the above design principle, in one of our specific cases, IMEN site (NIMTFGNSS-1 type time and frequency transfer receiver) has been selected as the time and frequency transfer system, because it is self-developed by NIM and can be implemented by any change to be adapted to our special use. For not only the general performance but also low cost and small size of the clock, we choose the Rubidium clock as the compromise in our present instance. User interface of the GNSS time and frequency transfer system referenced to the Rubidium clock can mainly show the results of time and frequency transfer for the single station that stand for the difference between the Rubidium clock and GNSST(GNSS system Time) and generate the corresponding Rfile files (specific time and frequency transfer data file in self-defined format for the single station) and so on.

One steering program is used to keep the Rubidium clock operated in a controllable way as to ensure its time and frequency output are stable and reliable by the steering algorithm in near real-time. Thus, NIMDO works in being steered by calibrating the Rubidium clock referenced to UTC(NIM) with the time and frequency differences between the Rubidium and UTC(NIM) in time.

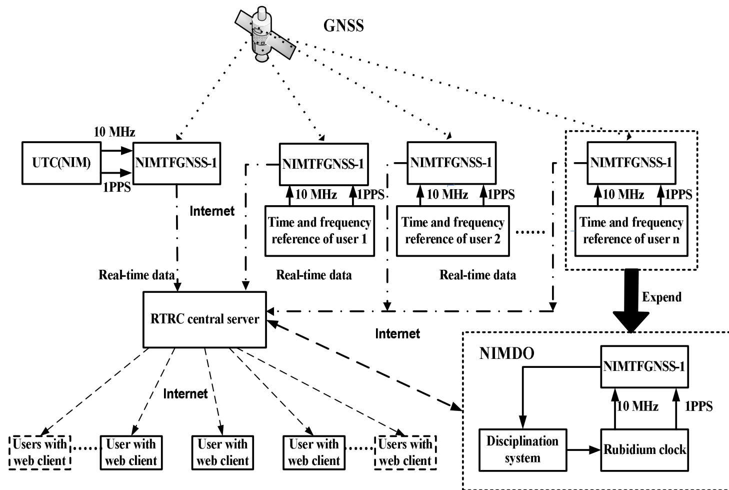

Fig. 1. Scheme of RTRC

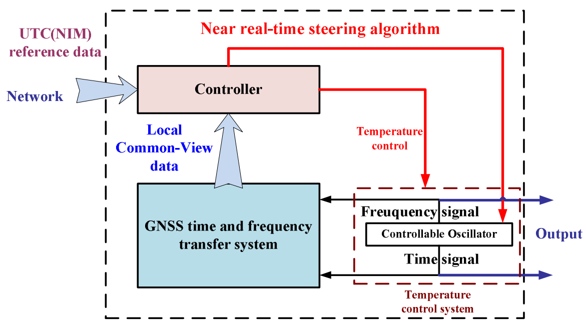

Fig. 2. Principle of NIMDO

Fig. 3. NIMDO aspect

It is necessary that there is one reference, UTC(NIM). The time and frequency transfer data of it are uploaded to the specific FTP server for NIMDO to download using the uploading and downloading programs every 16 minutes by FTP(File Transfer Protocol) way. Then NIMDO calculates the time and frequency difference between NIMDO and UTC(NIM) for the steering of NIMDO to UTC(NIM). But for several or multiple NIMDOs, we can and should just use this one reference for all of them as we are doing. In our case, we use IMEU site (NIMTFGNSS-1type time and frequency transfer receiver) for time and frequency transfer of UTC(NIM).

Finally, it is significant for NIMDO to transfer time. The time transfer link based on the GNSS time and frequency transfer receivers in the link between NIMDO and UTC(NIM) must be calibrated correctly and the calibration values can be traced to UTC(NIM) in the suitable uncertainty.

III. Steering Algorithm

The steering algorithm must be stable and reliable so that we can ensure NIMDO a certain degree of accuracy and precision in days or weeks, even months. We calculate the time differences between NIMDO and UTC(NIM) from the Rfile data of two stations, and then the frequency differences, and finally we estimate the adjustment values from the above information using some kind of PD(Proportion and Derivative) control. The adjustment value is usually the frequency correction that should be within some range matched to the noise level of the Rubidium clock. When the time difference is in some pre-defined range, the adjustment to NIMDO will be not often to guarantee the stability. In addition, some delays, such as network delay, should be considered as well and the linear combination of many elements forms the main time difference estimation equation to get more accurate time difference in terms of (1).

$$\Delta T_i = \Delta t_i + (\Delta t_i - \Delta t_{i-1}) \times \left(\frac{t_{\mathrm{tr}}}{2} + 1 + t_{\mathrm{d}}\right) \times \frac{1}{\tau} \qquad (1)$$

ΔT_i : total time difference between NIMDO and UTC(NIM) during the steering process in the *i*-th cycle of 16 minutes used;

Δt_i : CV time difference between NIMDO and UTC(NIM) obtained using the Rfile data from two sites in the *i*-th cyle;

Δt_{i-1} : CV time difference of obtained using the Rfile data from two sites in the cycle before the *i*-th cycle;

t_{tr} : tracking time, which is 13 minutes;

t_d : estimated time delay of network, which is one or two minutes;

τ : Sampling period, which is 16 minutes.

During the steering, there are two procedures. One is to adjust phase and the other is to adjust frequency by sending of the corresponding command codes. Because initially the time difference between NIMDO and UTC(NIM) is usually large, we can adjust the phase of rubidium clock after we get ΔT_i from (1). Phase adjustment is a direct but unstable way. After the phase adjustment, we need frequency adjustment to keep NIMDO in a smooth path. According to the relationship between time difference and relative frequency deviation, the frequency adjustment value can be obtained using (2).

$$\frac{\Delta f}{f_{\mathrm{UTC(NIM)}}} = \frac{f_{\mathrm{Rb}} - f_{\mathrm{UTC(NIM)}}}{f_{\mathrm{UTC(NIM)}}} = \frac{\Delta T_i - \Delta T_{i-1}}{\tau} \quad (2)$$

Δf : relative frequency deviation;

f_{Rb} : frequency of the local rubidium clock;

$f_{\mathrm{UTC(NIM)}}$: frequency of UTC(NIM) which is 10MHz.

IV. NUMRIC RESULTS

The NIMDO and UTC(NIM) are separately located at the Hepingli campus and the Changping campus at NIM with the baseline about 40 km. Some experiments have been done for performance verification and evaluation of NIMDO. We use some results including time and frequency difference with reference to UTC(NIM) by GPS(Global Positioning System) CV to verify the time and frequency accuracy and use some of their statistics such as TDEV(Time Deviation) and MDEV(Modified Allan Deviation) for the proof of the time and frequency stability. The direct comparison with the free-running Rubidium clock and the Cesium clock by one phase comparator were implemented for the characterization of the advantages of steering.

A. Perfomance with Reference to UTC(NIM) by GPS CV

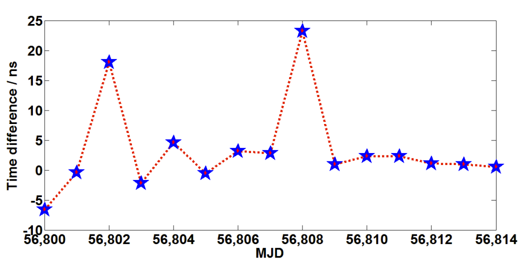

Fig. 4. Daily time difference from UTC(NIM)

The time and frequency transfer system for UTC(NIM) is IMEU. The results are based on the GPS C/A code measurements. The time and frequency differences during half a month from MJD 56800 to 56814 are shown in Fig. 4 and 5. Compared to UTC(NIM), the time and frequency daily difference are separately most within 20 ns and 1e-13 and the average values during this period are separately 3.4 ns and 6.0e-15.

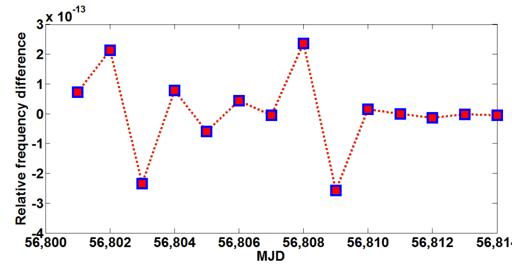

Fig. 5. Daily frequency difference from UTC(NIM)

TDEV and MDEV are separately illustrated in Fig. 6 and 7. We can see that time and frequency stability for one day are separately about 3 ns and 6e-15, and when averaging time is longer than two days these values can almost approach sub-nanosecond and 10^{-15} level. We compare the above MDEV results of NIMDO with the factory specifications of two kinds of 5071A with standard tube and with high performance tube in Fig. 8. We can see that NIMDO shows better stability than the other two clocks over one day averaging.

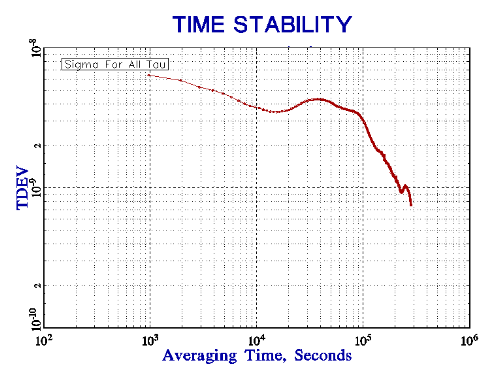

Fig. 6. Time stability of NIMDO

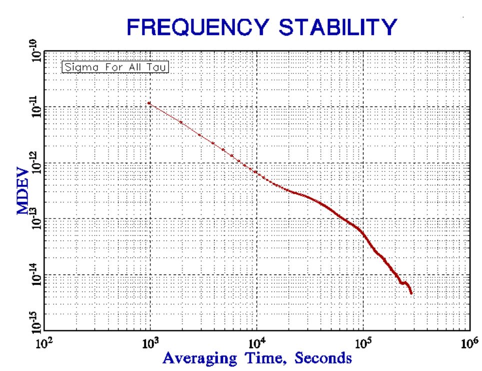

Fig. 7. Frequency stability of NIMDO

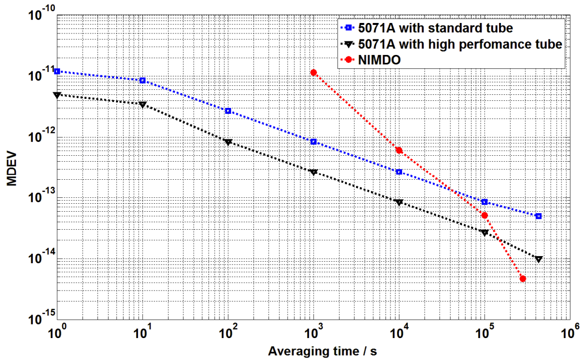

Fig. 8. Comparion among NIMDO and 5071As in frequency stability

B. Direct Comparison with the Cesium Clock and the Free-running Rubidium Clock

With reference to UTC(NIM)_Hepingli based on one Cesium clock (Symmetricom 5071A with high performance tube) at the Hepingli campus, one Cesium clock (Symmetricom 5071A with high performance tube) and NIMDO were compared by one phase comparator (VCH 314). After 13 hours, we can acquire that the averaging frequency difference between NIMDO and UTC(NIM)_Hepingli is -1.1e-14 using 100-s interval data and the Cesium clock is differenced by -2.1e-13 from UTC(NIM)_Hepingli. The results might say that the accuracy of NIMDO traced to UTC(NIM) in near real time could be better than the Cesium clock.

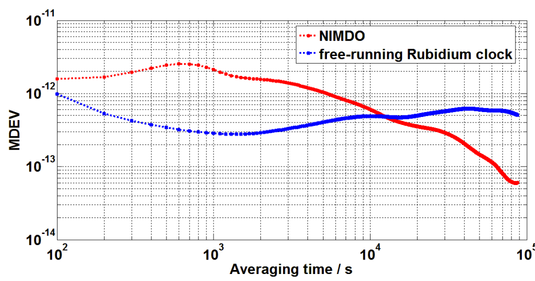

Fig. 9. Comparison between NIMDO and free-running Rubidium clock

Concerning the frequency stability, we compared NIMDO and the free-running Rubidium clock referenced to the Cesium clock by the phase comparator as well, however we just have four whole days from MJD 56821 to 56825 for the experiment and the results with averaging time no longer than one day is described in Fig. 9. The obvious goodness can be acquired thanks to the improvement of the stability averaging time longer than three hours by the appropriate steering.

V. SUMMARY AND PROSPECTS

UTC(NIM) disciplined oscillator, NIMDO, has been studied and implemented. By verification, we can conclude that the time and frequency accuracy of NIMDO could separately be better than 5 ns and 1e-13 averaging one day, and the time and frequency stability averaging one day could separately be better than 5 ns and 6e-14. In other words, in general, its accuracy could be better than one Cesium clock such as one Symmetricom 5071A with high performance tube and its long term stability can be improved obviously compared to the free-running Rubidium clock. The time and frequency accuracy of NIMDO has been improved thanks to the high level reference time scale and time scale algorithm and its long stability has been ameliorated due to the near real-time and short latency steering to UTC(NIM).

Soon we will lay up four NIMDOs at four cities (Urumchi, Guiyang, Harbin, and Beijing) in China to reveal the longer baseline effects. Since 2012, BIPM(Bureau International des Poids et Mesures) has given the more emphasis on prediction of the atomic clocks, so the steering algorithm should be improved towards this direction for the better dynamic performance of NIMDO. In near future, based on some study (see some information in [4]) and application on time and frequency transfer by BDS(Beidou Navigation Satellite System) and multiple GNSS systems, we would enhance the measurement accuracy and stability. We are trying to lower the noise of time and frequency transfer system in NIMDO by using GPS carrier phase method in near real time. Certainly, on the basis of the present NIMDO principle, we could study and form the NIMDO based on the Cesium clock, the Hydrogen maser, or some other atomic clock to meet the application with the higher level requirements.

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