VLBI Application for Time and Frequency Transfer and Comparison With Other Techniques

M. Sekido, T. Hobiger, R. Ichikawa, M. Fujieda, T. Gotoh, J. Amagai,
K. Takefuji, and H.Ujihara
1)National Institute of Information and Communications Technology(NICT), Japan

1.Introduction.

Development of optical frequency standards is progressing rapidly and its accuracy (uncertainty of the absolute frequency) is reaching about 10^{-16} in fractional frequency. Current atomic time standard with Cs atoms will be replaced by optical frequency standards in the near future. Inter-comparisons of the generated frequencies between laboratories are necessary in order to make time-scale defining sources of next generation. However these frequency standards are operated in a carefully controlled environment in each laboratory, and thus cannot be moved and compared directly against a clock on another site. Optical fiber-linked frequency transfer has been realized for distances around 100km, and its frequency comparison precision is better than 10^{-15}(Fig.1). However, high precision time & frequency (T&F) transfer over intercontinental distances does not reach sufficient precision to support such a clock performance. T&F transfer techniques have been used for inter-comparison of locally generated UTC among independent laboratories for maintaining national time standards. In this paper, several technologies used for T&F transfer are introduced, and we propose to use VLBI as an tool for T&F transfer.

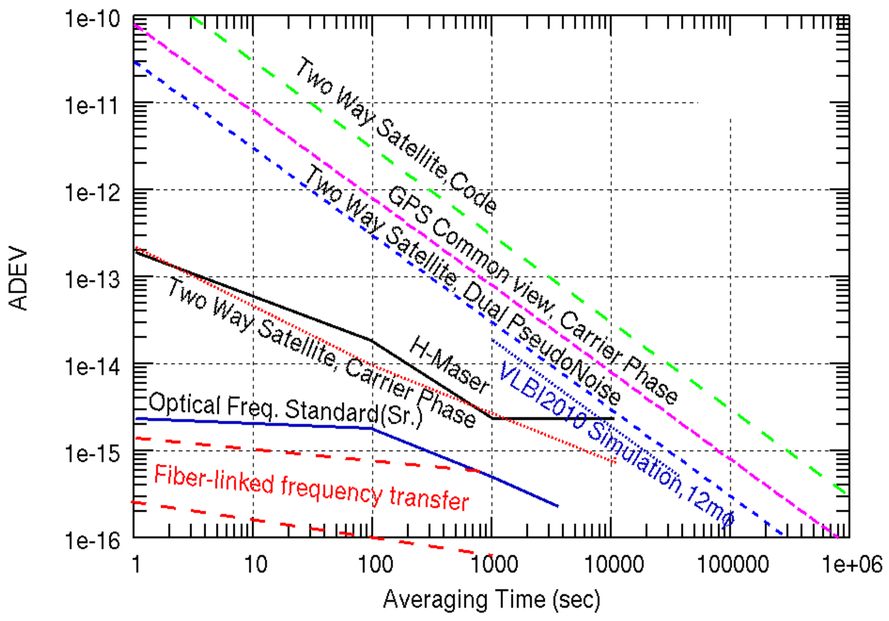
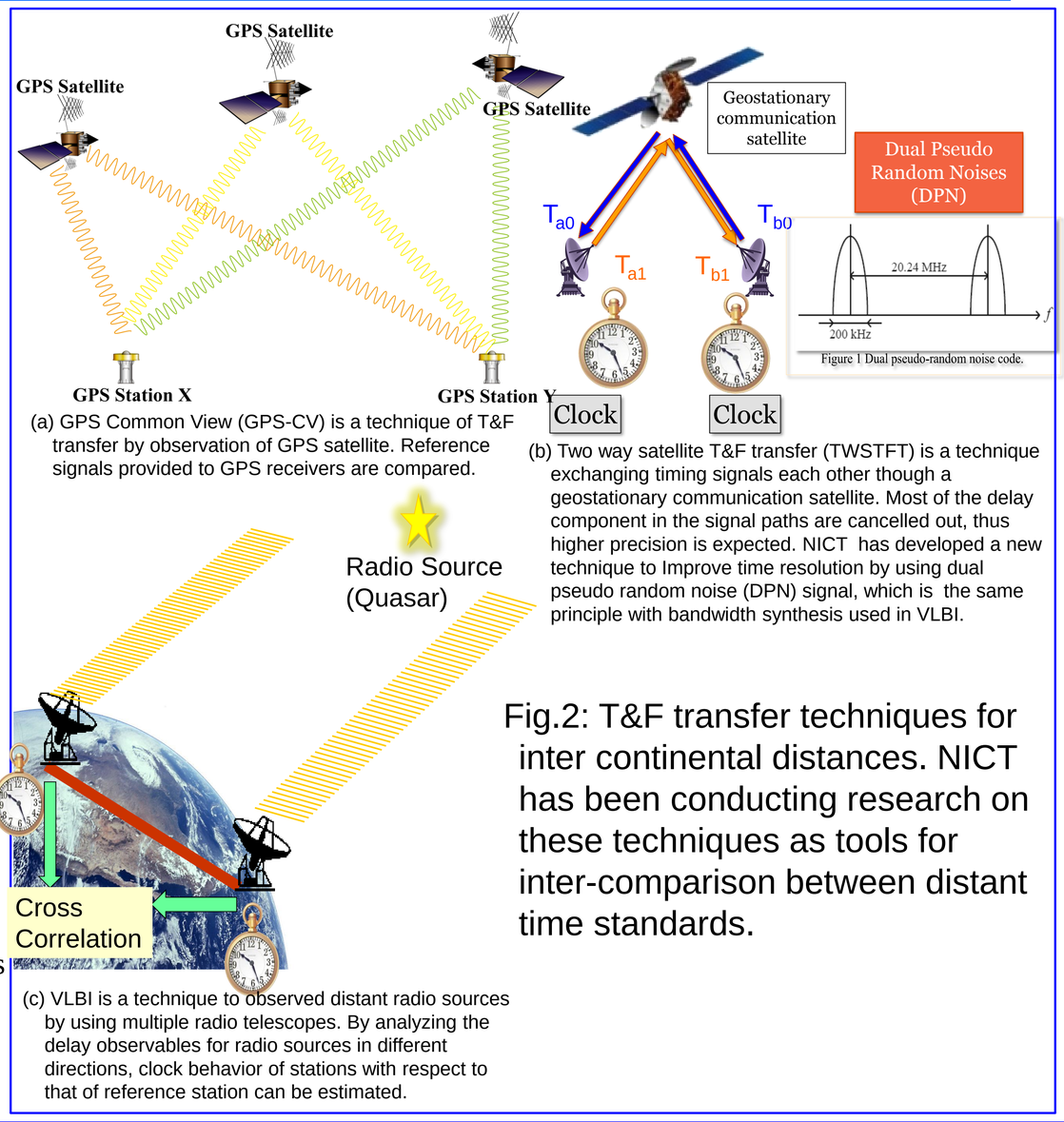


Fig.1: Typical stabilities of long distance T&F transfer techniques and stabilities of atomic time standards.

2. Long Distance T&F Transfer Techniques

NICT has been developing several T&F transfer techniques including optical fiber link, two-way satellite link, and others. Here we discuss only those applicable for intercontinental distances here. Typical time comparison stabilities for each techniques are indicated in Fig.1. An overview of the three techniques for long distances is displayed in Fig.2.



(a) GPS Common View (GPS-CV) is a technique of T&F transfer by observation of GPS satellite. Reference signals provided to GPS receivers are compared.

(b) Two way satellite T&F transfer (TWSTFT) is a technique exchanging timing signals each other though a geostationary communication satellite. Most of the delay component in the signal paths are cancelled out, thus higher precision is expected. NICT has developed a new technique to Improve time resolution by using dual pseudo random noise (DPN) signal, which is the same principle with bandwidth synthesis used in VLBI.

Figure 1 Dual pseudo-random noise code.

(c) VLBI is a technique to observed distant radio sources by using multiple radio telescopes. By analyzing the delay observables for radio sources in different directions, clock behavior of stations with respect to that of reference station can be estimated.

Fig.2: T&F transfer techniques for inter continental distances. NICT has been conducting research on these techniques as tools for inter-comparison between distant time standards.

3. T&F Transfer Experiments

T&F transfer experiments have been conducted on Koganei(Tokyo)-Kashima(Ibaraki) 100km distance to compare the performances of the techniques (Fig.3). The Japanese time standards (JST) is maintained by NICT at Koganei, and H-maser signal synchronized with JST was provided to Koganei station for reference. Another H-maser frequency standard is located in Kashima. The difference of the two atomic standards were compared with TWSTFT, GPS, and VLBI. Fig.4-6 show the results of the comparison experiments, where a parabolic curve due to clock behavior was commonly removed in the plot of each experiment. Arbitrary clock offsets were removed as well from each data set so that measurement data were easily compared in the plots.

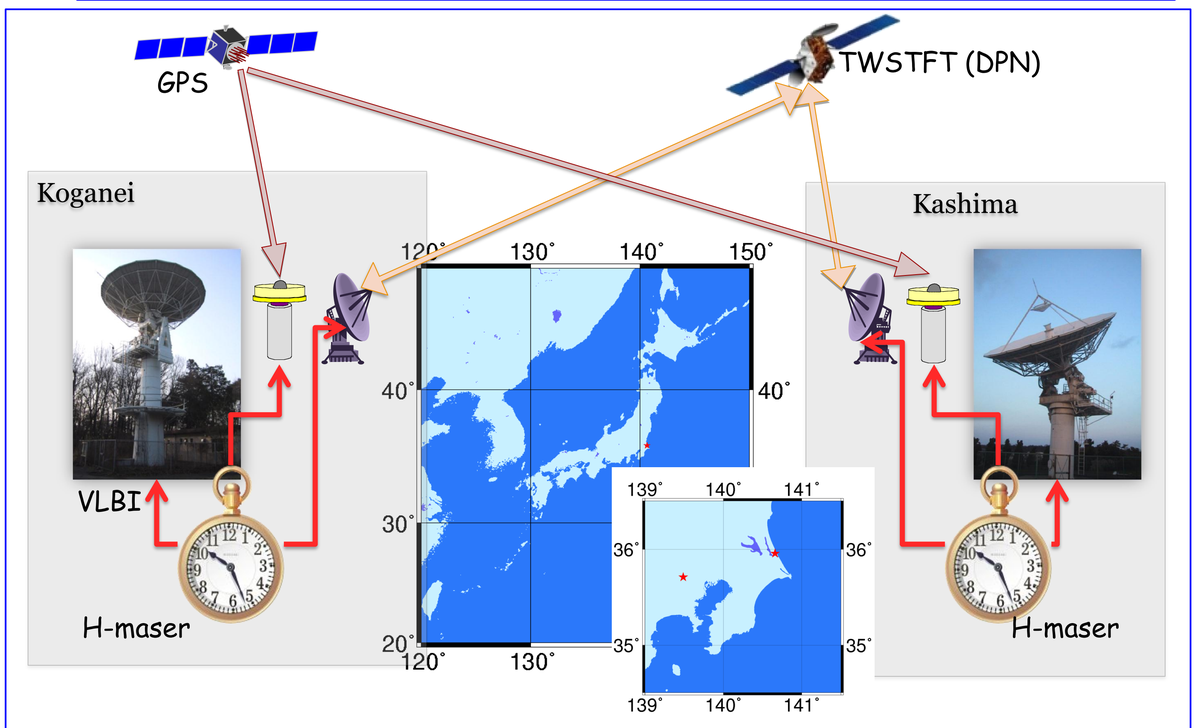


Fig.3: Experiments for comparison of the T&F transfer techniques at Kashima 11m site and Koganei NICT headquarter have been organized. Simultaneous observation with TWSTFT, GPS common view, and VLBI were made with the same H-maser atomic time standards at each sites.

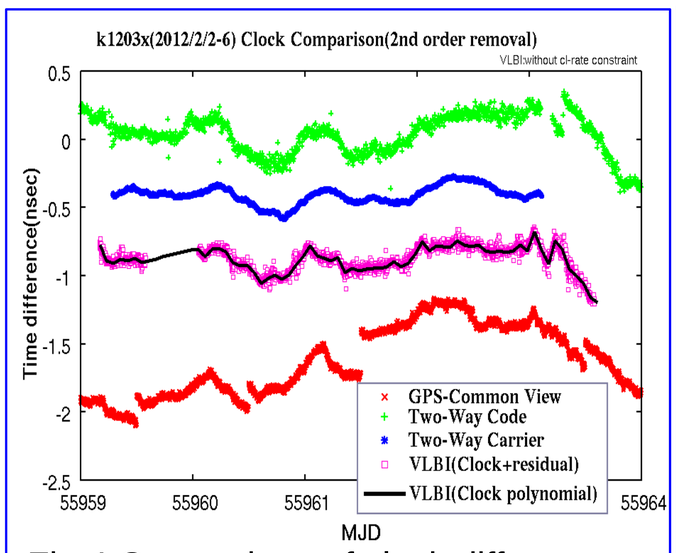


Fig.4:Comparison of clock difference measured by TWSTFT, GPS, and VLBI in 2-6th Feb 2012.

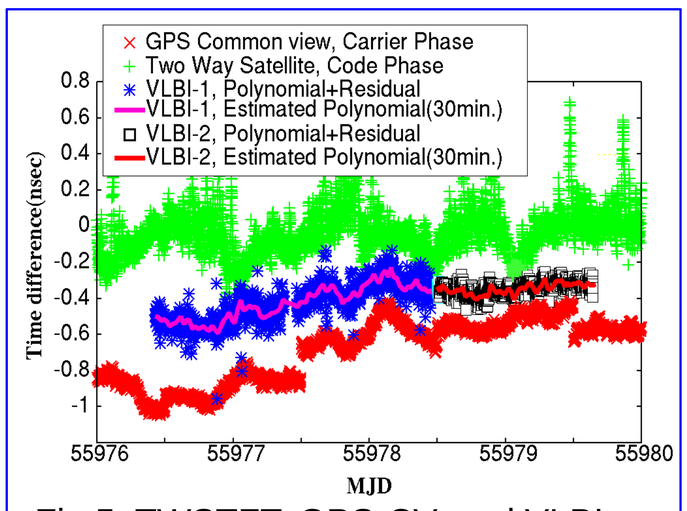


Fig.5: TWSTFT, GPS-CV, and VLBI comparison in 19-23rd Feb. 2012.

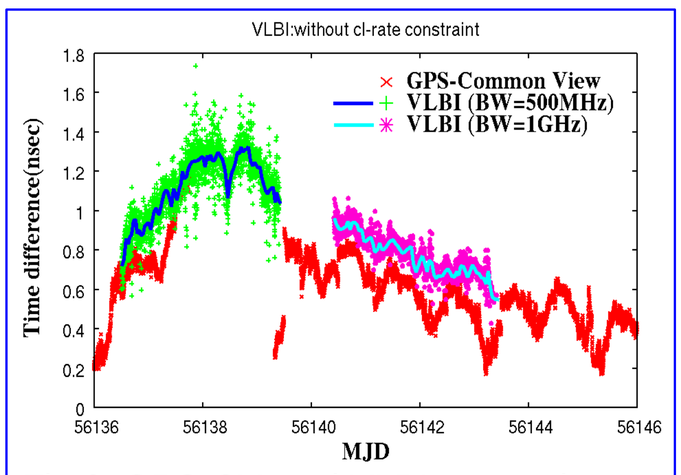


Fig.6: GPS-CV, and VLBI comparison on in 28th Jul. – 4th Aug. 2012.

[EXP2012Feb.2-6](Fig.4) Clock behavior difference were compared for 5 days between H-maser standards at Kashima and Koganei via GPS-CV, TWSTFT(Code), TWSTFT(Carrier Phase), and VLBI(BW=1 GHz). Clock jumps of GPS-CV data at day boundary are due to discontinuity of satellite orbit information.

[EXP2012Feb.19-23](Fig.5) Clock comparison experiment was made with GPS-CV, TWSTF(Code), and VLBI(BW=500 MHz, 1 GHz). Comparing VLBI data between 500MHz bandwidth and that of 1GHz bandwidth, the increase of bandwidth shows improvement of the precision of clock difference measurements. This is encouraging the development of ultra-wideband VLBI (Gala-V) system, where much higher delay precision is expected.

[EXP2012Jul.28-Aug.4](Fig.6) Techniques of GPS-CV and VLBI (BW = 500 MHz, 1 GHz) were compared. Advantages of higher precision in wideband observation (VLBI) were not obvious in this time. Cause of this must be investigated.

4. Development of a New Ultra-Wideband VLBI system ('Gala-V')

A project to develop ultra-wideband (3-14GHz) VLBI system ('Gala-V') is in progress for VLBI application for T&F transfer. After RFI surveys, four frequency bands at 3.7, 5.3, 10.1, and 13.3 GHz with 1GHz bandwidths were selected for observation bands. Combined use of the Gala-V and transportable small diameter antennas(Fig.7) is planned for long distance T&F transfer. The Gala-V system is in the framework of next generation VLBI system design 'VLBI2010', which is proposed by IVS. Thus joint observation with VLBI2010 system is in the scope of the project. Fig.8 shows the evaluation of VLBI2010 system for T&F comparison, which is plotted in Fig.1.

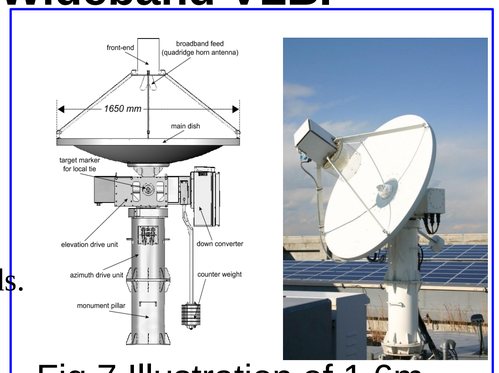


Fig.7 Illustration of 1.6m antenna (Gala-V) system.

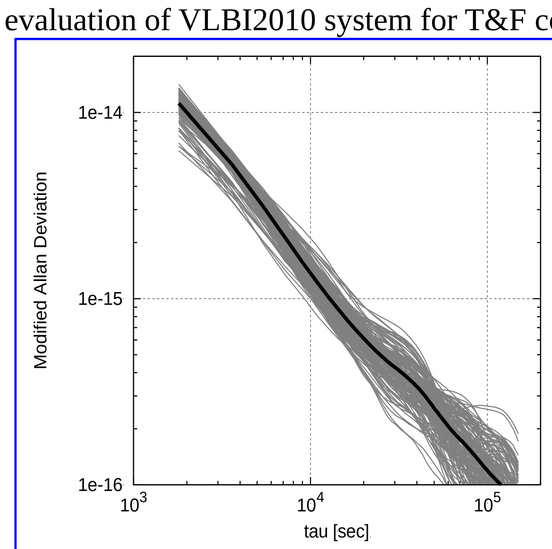


Fig.8: Simulation to evaluate the performance of VLBI T&F comparison.

Simulation Condition

- Measurement uncertainty 10 ps (white noise), i.e. 3x the specified accuracy of the fully operational VLBI2010 system
- Troposphere turbulence with $C_n = 10^{-7}$, H=2000 m (Nilsson and Haas [2008])
- Station clocks: 10^{-16}@1d (Next-generation freq. standards)
- Analysis (least squares adjustment):
  - Station coordinates fixed
  - Estimate: troposphere and station clocks
  - Compute difference estimated – simulated clock (i.e. access the true TFT capability)
  - Derive freq. stability over all possible baselines