Development of A Wide Band Very Long Baseline Interferometry System for Time and Frequency Comparison on Intercontinental Distances.

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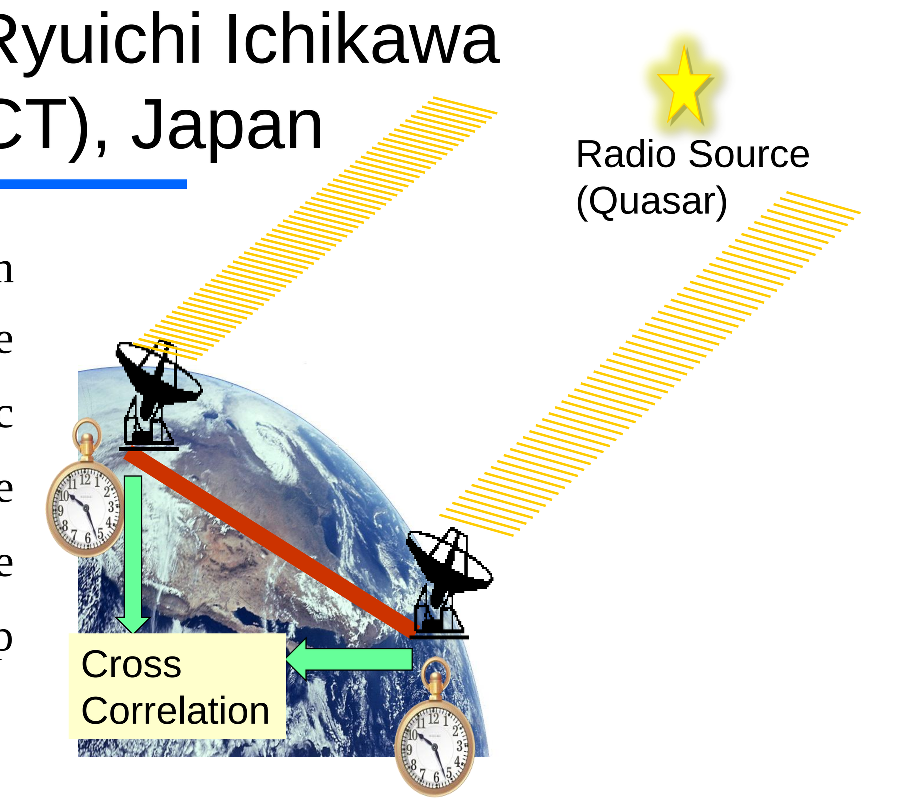


1.Introduction.

Very Long Baseline Interferometry (VLBI) has the capability to measure the baseline vector between radio telescopes on intercontinental distances. However, it has also the potential of utilizing this technology for the comparison of atomic frequency standards which are separated by several 1000s of kilometers. Fig.1 shows a result of time comparison with VLBI, GPS and TWSTFT between two hydrogen maser atomic frequency standards located at Koganei in Tokyo and Kashima, which are separated by 100 km distance. This experiment demonstrates that the scattering as measured with VLBI in a 1GHz band width mode (black open squares) is reduced in comparison to VLBI with a 0.5 GHz bandwidth (blue closed circles) by factor of $1/\sqrt{2}$, which is exactly predicted by the ratio of the observation bandwidth. This indicates that the precision of VLBI group delay measurement is still dominated by random noise, thus it can be improved by expanding the observation bandwidth.

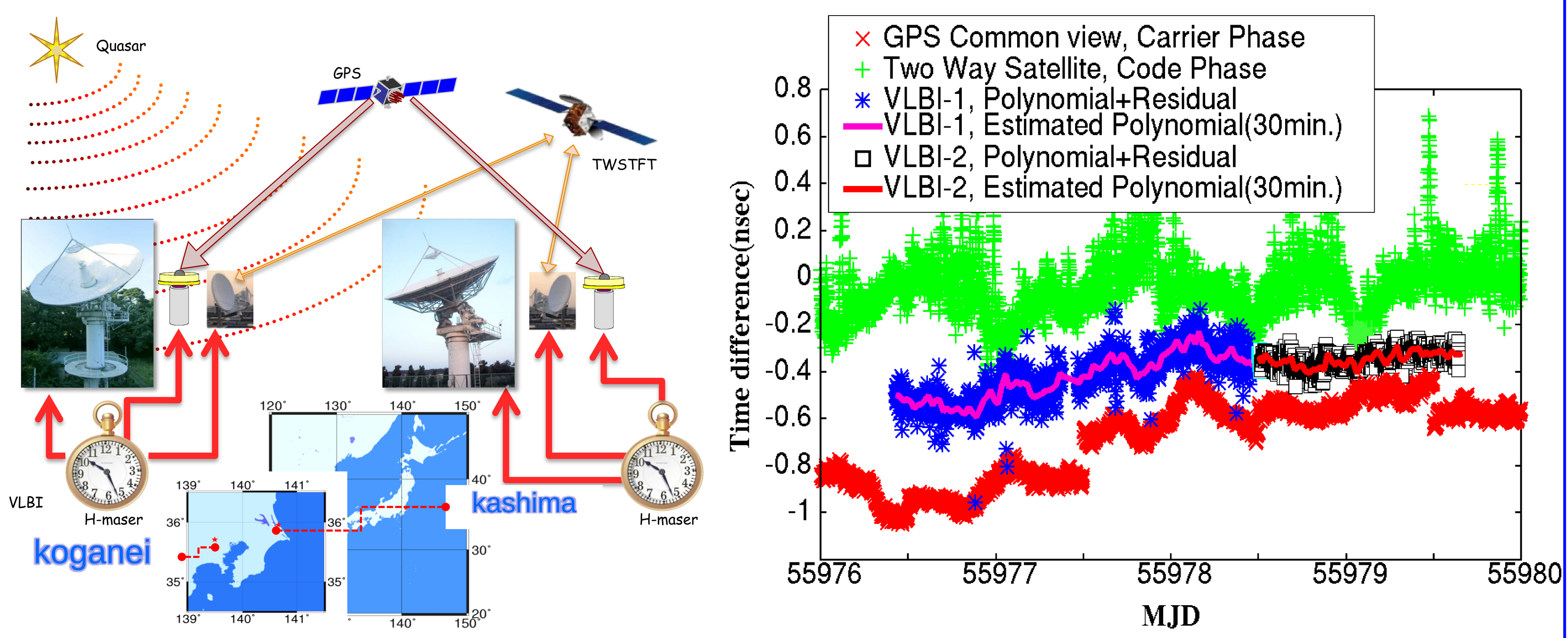


Fig.1. Experiments for comparison of the T&F transfer techniques at Kashima 11m site and Koganei NICT headquarter have been organized in 19-23rd Feb. 2012. Simultaneous observation with TWSTFT, GPS common view, and VLBI were made with the same H-maser atomic time standards at each sites. VLBI observation with 0.5GHz bandwidth yielded WRMS 23ps, and it was improved to 17 ps with 1GHz bandwidth.

2. Concept of the VLBI application for T&F Transfer.

The basic concept of the T&F transfer with VLBI system is displayed in Fig.2. To enable VLBI observation at local site of the atomic frequency standards to be compared, transportable small diameter antenna pairs are required. The disadvantages of the small correcting area of radio signal from celestial radio sources is compensated by ultra wide-band receiver system and joint observation with larger diameter antenna. Signal to noise ratio of VLBI observation is proportional to the products of diameter of the antennas D_1, D_2 and observation bandwidth B as presented by the formula $SNR \propto SD_1D_2\sqrt{2Bt}$. Observation bandwidth be 4 GHz and dual polarization, which is about 32 times larger samples than conventional VLBI observations. Thus 1.6m diameter antenna become equivalent with 9 m diameter antenna theoretically. This wide band observation system design has been proposed as "VLBI2010" by the International VLBI Service for Geodesy and Astrometry (IVS)[1][2].

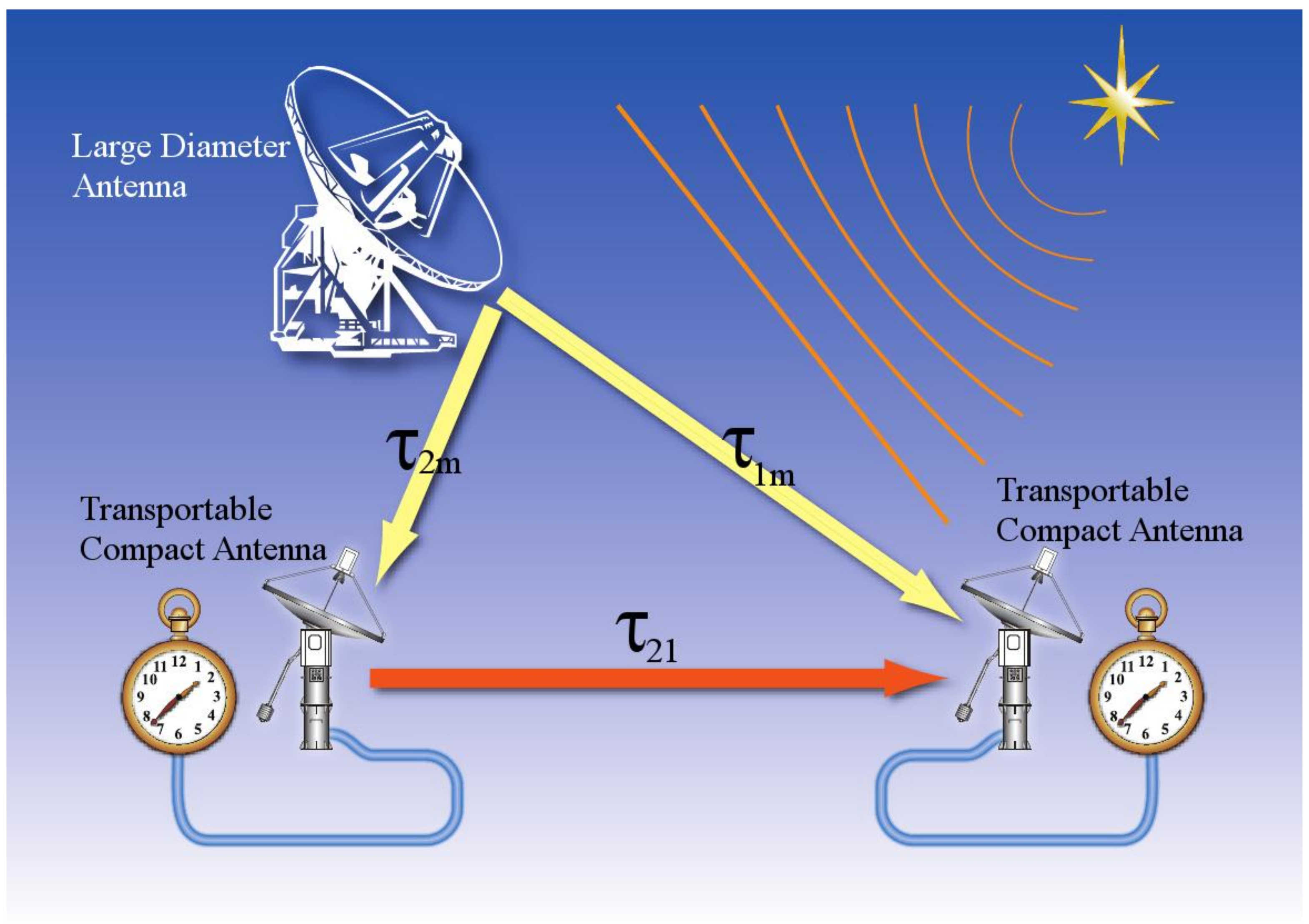


Fig.2. Concept of the T&F transfer with VLBI. Transportable small diameter antenna pair will work by using the reference frequency from atomic frequency standards. The comparison of distant atomic frequency standards is made via VLBI observations between larger diameter antenna and small antenna pair. Large diameter antenna is for improvement of the sensitivity of VLBI observation.

3. Development of Wide Band VLBI System (Gala-V).

For the purpose of VLBI based frequency comparison, we are developing a new wideband VLBI system named GALA-V which has similar specifications with the next generation wideband VLBI observation system 'VLBI2010'[1]. Fig.3 shows the transportable 1.6m radio telescope which has been designed to be easily assembled/disassembled. The GALA-V system will include a pair of these small antennas and medium size antenna (11m or 34m). Our system has fixed observation frequencies at 3.2-4.2GHz, 4.8-5.8GHz, 9.6-10.6GHz, and 12.8-13.8GHz. The frequency arrangement was decided by taking into account **better delay resolution function(Fig.4)**, radio interference conditions based on field surveys, and making use of the **direct sampling technique(Fig5)**, i.e. signals are digitized without frequency conversion by taking advantage of the aliasing effect. All of these design choices contribute to a cost reduction of the system. The anticipated precision of the delay measurements in combination with a 34m or a 11m telescope is around 6 -- 8 ps for a single observation with an integration time between 7 – 40 sec. Fig.2 shows a simulation to evaluate the feasibility of VLBI2010 system for frequency comparison. Test observations with this prototype system will start in 2013.

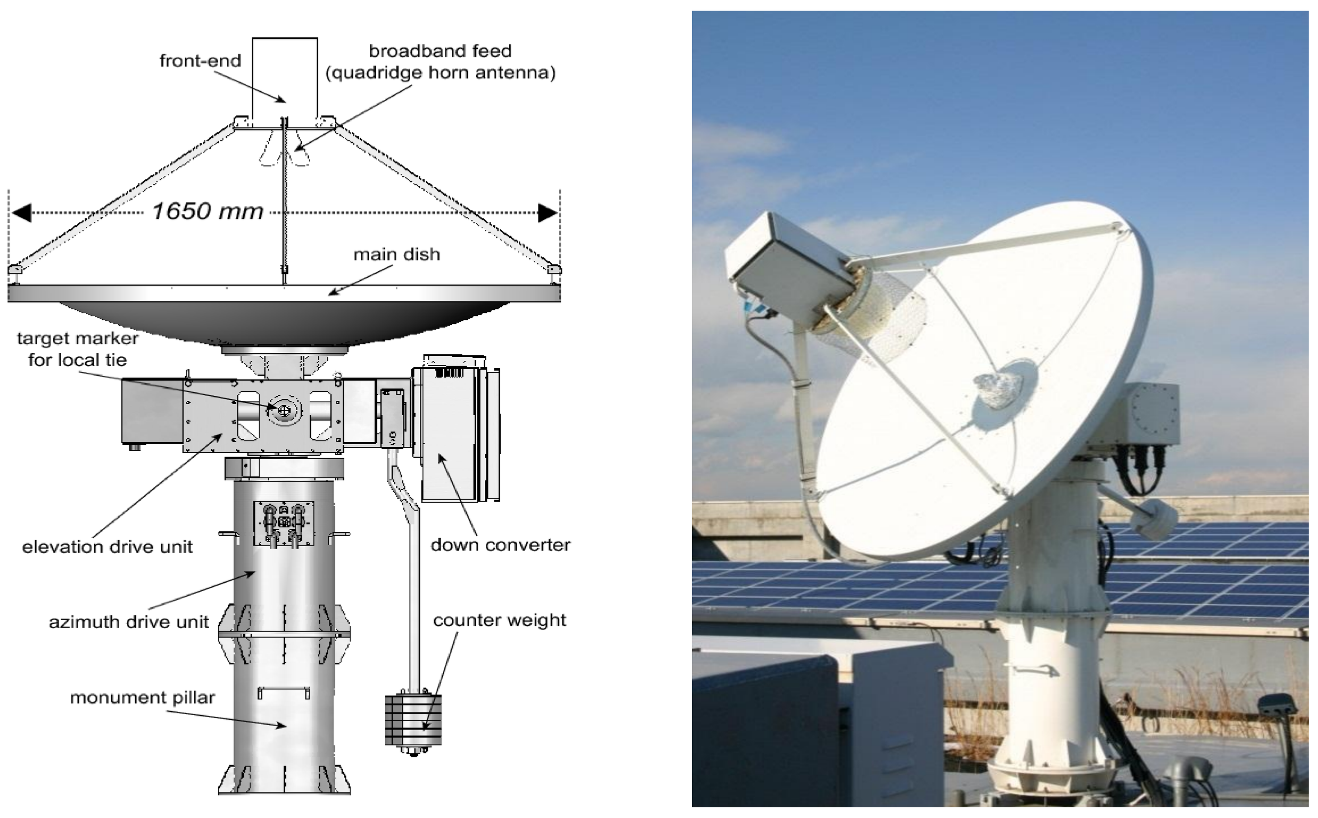


Fig.3 Outlook of 1.6m antenna for the wideband VLBI system Gala-V.

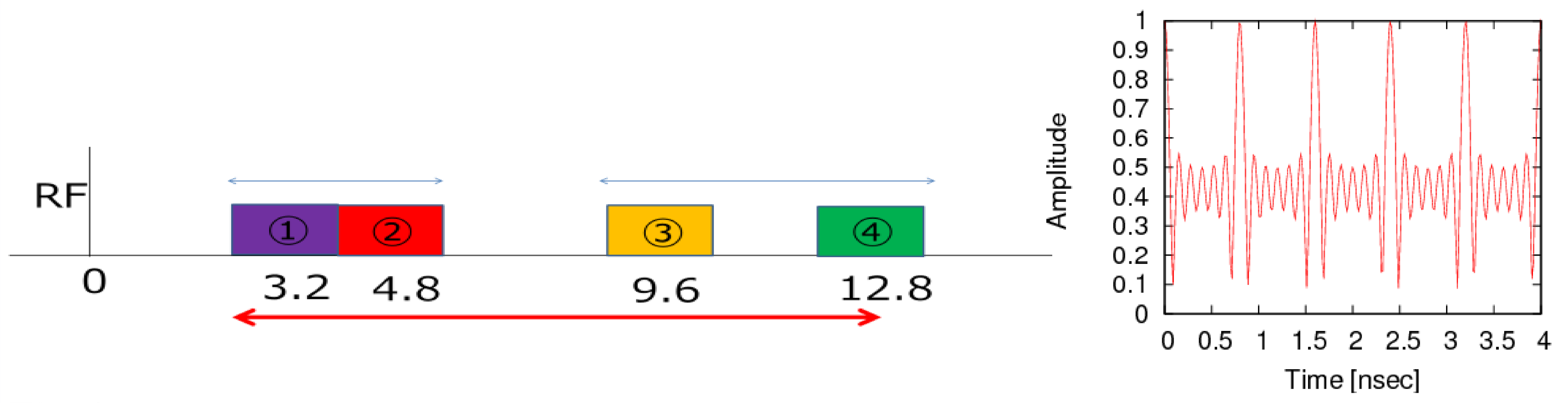


Fig.4 Shape of the delay resolution function is determined by the frequency array to be synthesized. The best array coordination is known to be achieved by zero-redundancy array, where ratio of the array interval is composed of prime number. We have chosen the multiple of 1.6 GHz for the interval of the array. Left panel shows the observation bands on the frequency axis. This frequency array yield the delay resolution function indicated in the right panel.

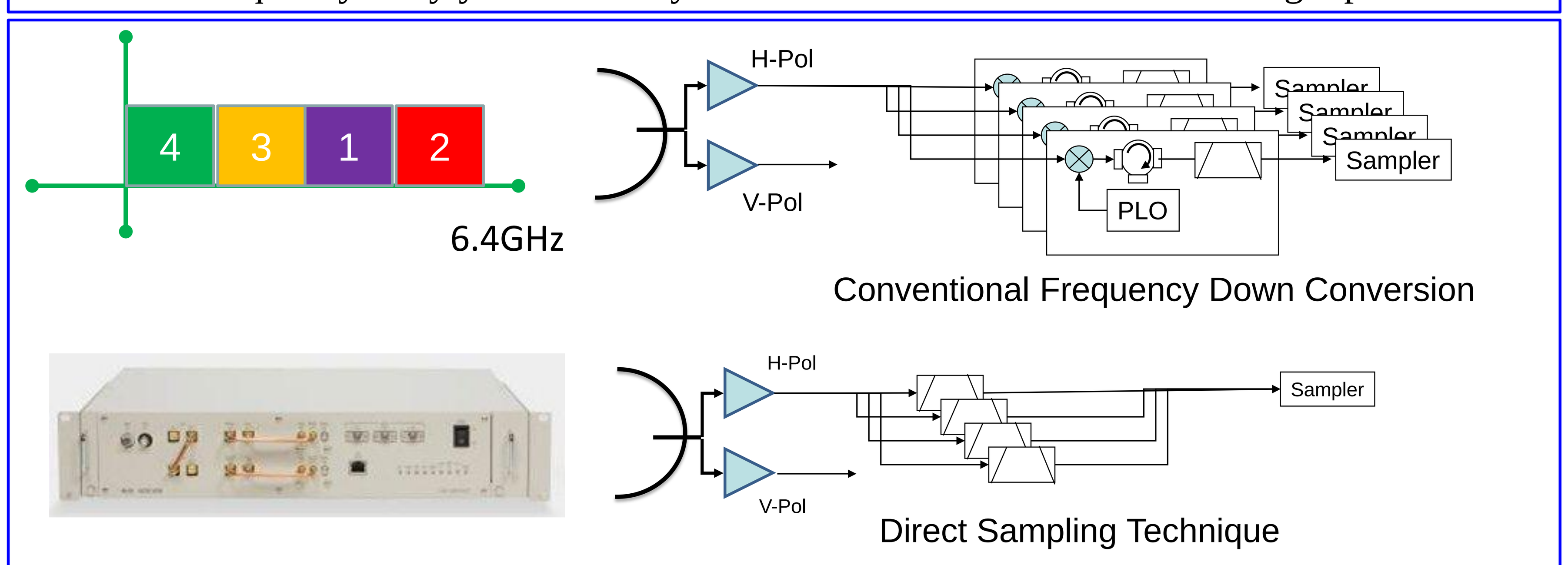
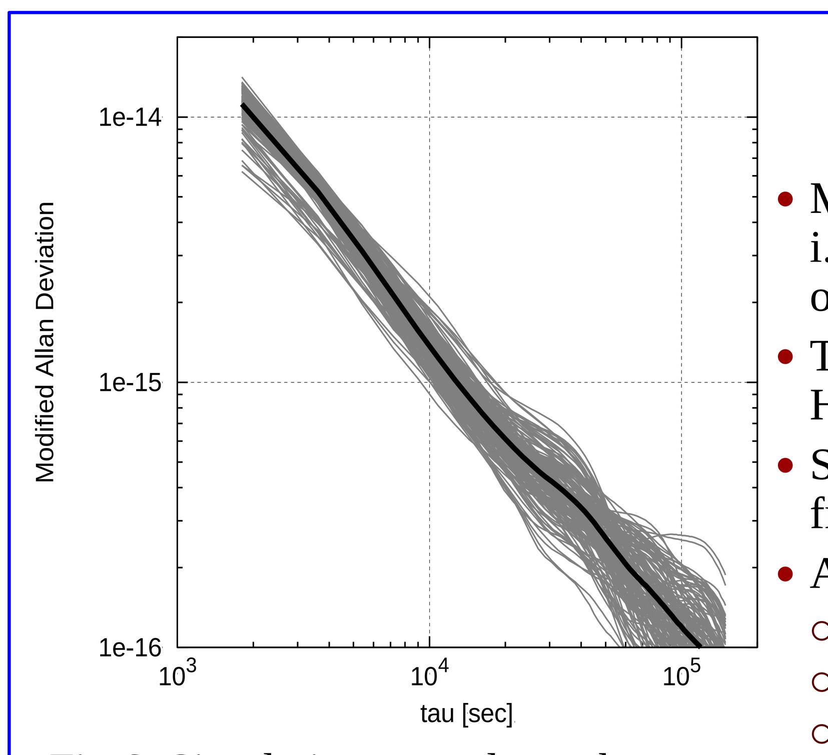


Fig.5. By using the aliasing effect of the sampling theorem, all the four bands of the signal is acquired by 6.4 GHz sampling at once. Therefore conventional frequency conversion system can be avoided in this case. Upper left panel is frequency allocation after the direct sampling of the signal in Fig.2. Lower left is the prototype of the high-speed A/D machine.



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

Fig.6: Simulation to evaluate the performance of VLBI T&F comparison.

[1] Petrachenko B. Et al., "Design Aspects of the VLBI2010 System", NASA/TM-2009-214180 (2009).
[2] http://ivscc.gsfc.nasa.gov/technology/vlbi2010-general.html