Development of Wideband VLBI System with Transportable Small Telescope for Distant Frequency Transfer

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Abstract

Very long baseline interferometry (VLBI) is one of the technologies to enable comparisons of atomic frequency standards at intercontinental baseline. Our group is working on development of wideband VLBI system with transportable small diameter antennas for VLBI application to the frequency transfer. The system is composed of pair of small diameter antennas and large diameter antenna, which observes ultra-wide frequency range at 3-14GHz. This paper reports the overview of the project and current status of the development.
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1. Introduction

Following to the progress of optical frequency standards development, precise frequency comparison at long distances is getting important. In addition to well-known T&F transfer techniques such as TWSTFT (two way satellite time and frequency transfer), GNSS common view, and T2L2, very long baseline interferometry (VLBI) has capability to compare the atomic frequency standards at intercontinental distances. National Institute of Information and Communications Technology (NICT) is working on development of wideband VLBI observation system (named 'Gala-V') composed of a pair of small transportable VLBI stations and large diameter VLBI station (Fig. 1). Disadvantage of the small correcting area of small antenna is compensated by large bandwidth and co-observation with large diameter antenna. VLBI is technique to observe celestial radio sources with more than two radio telescopes. Signal to noise ratio (SNR) of single baseline VLBI observation is proportional to the product of the diameters of the two antennas and square root of the bandwidth. Therefore even small diameter antenna could be used for VLBI observation of weak radio sources by combination use with large diameter antenna and by using large observation bandwidth.

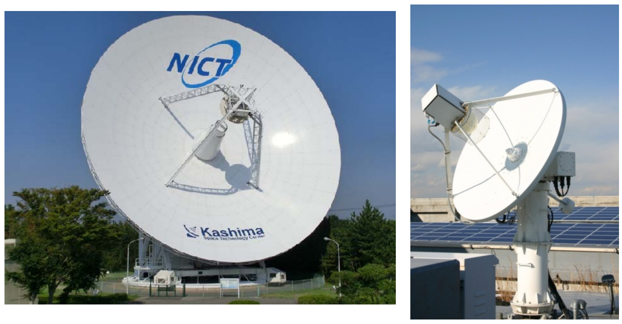

Figure 1, Kashima 34m antenna (Left) and 1.5-m parabolic antenna (right) are the components of the Gala-V system.

The Gala-V system observes four microwave bands with 1GHz bandwidth in 3-14 GHz frequency range for each dual linear polarization. That radio frequency coverage coincides with that of the next generation geodetic VLBI system, so called VGOS. Future co-observation with global VGOS stations is in the scope of this Gala-V project.

2. Technology Development for Wideband Gala-V System.

The new wideband VLBI system Gala-V is using several new technologies to achieve higher precision and lower costs. Frequency array was selected by taking into account the radio frequency interferences (RFI) and delay resolution function formed by coherent synthesis of the wideband signal. Designing of wideband receiver feed for large diameter cassegrain parabola antenna is a challenge. Direct sampling technique is employed and being tested in the project.

2.1 Observation Frequency Array

Delay measurement precession is inversely proportional to the effective bandwidth (root mean square of frequency channel array). Effective bandwidth of the Gala-V system is about 3GHz, where which of conventional geodetic VLBI is about 0.3 GHz. Thus about one order of measurement precision improvement is expected. Table 1 shows the parameters of the Gala-V observation System. The observation frequency array was chosen with based on local RFI survey and consideration on delay resolution function. The RFI survey has been performed at Kashima, Tokyo, and Tsukuba. Delay resolution function is obtained by Fourier transformation of the correlated signal from frequency domain to time domain. The sharp peak without ambiguity of the wave-form is the key to get high resolution delay measurement. Blue line in the Fig.2 shows the delay resolution function expected by the Gala-V system.

Table 1, System parameter of the Gala-V System

Diameter of the Antenna	34m, 1.6m, 1.5m
Observation Frequency	3500-4524 MHz 5100 – 6124 MHz 9900 – 10924 MHz 13100 – 14124 MHz
Bandwidth per Channel	1024 MHz
Number of Channels	4
Effective Bandwidth	3.8GHz
Polarization of the radio signal	Linear Polarization V H

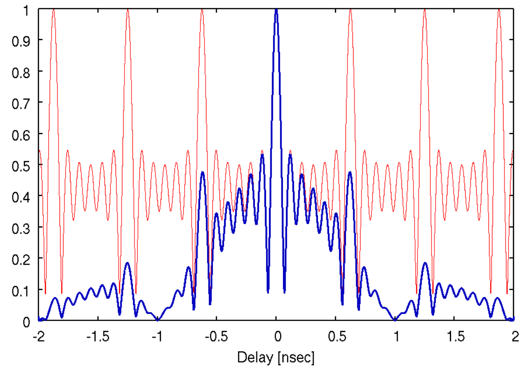

Figure 2, Blue line indicates delay resolution function computed from the frequency array of the Gala-V system in Table 1 with 1 GHz bandwidth. Red line indicates cycle ambiguity.

2.2 Wideband Feed for Cassegrain Parabola Antenna

Since Gala-V system needs more than two octaves of frequency range, Quad Ridge Horn Antenna (Fig. 3), which has 2-18GHz frequency range, has been installed in the small diameter antennas. Generally wideband feed has wide beam width around 90 degrees to 120 degrees. However, large diameter cassegrain antenna requires narrow beam width, which is 35 degrees for Kashima 34m antenna. Then we have developed wideband feed with narrow constant beam-width. The first test feed with 6.4-15GHz frequency coverage (Fig. 3) has been mounted on the Kashima 34m antenna in Jan. 2014. Dual Methanol maser line emissions at 6.7GHz and 12.2GHz were simultaneously observed from radio source W3OH. This feed was made for manufacturing test, and that for real use is under development with targeting 2.2-18 GHz observation frequency range.

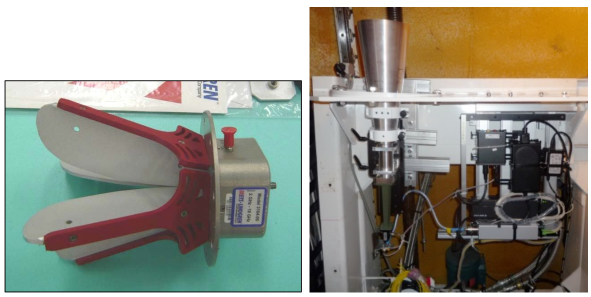
Figure 3, Quad Ridge Horn Antenna (Left) has 2-18GHz observation frequency range . This is used for 1.5-m and 1.6-m antenna. Right panel shows the new wideband feed, which has 6.4-15GHz frequency range, installed in the receiver room of Kashima 34m antenna.

2.3 RF Direct Sampling Technique

Conventional radio astronomy antenna employs analog frequency conversion for data acquisition. We have introduced high speed sampler (named K6/OCTAD-G, code name 'GALAS') for RF direct sampling method in the Gala-V system. Making use of RF direct sampler can eliminate the stuff and cost of analog frequency converter. Data is sampled with 16.384 GHz and signal with 1 GHz bandwidth at any specified frequency in the band can be extracted with digital filtering function implemented in FPGA circuit of the sampler. Sampling timing jitter and input signal frequency response have been evaluated. The RMS jitter was 0.2

Table 2, Typical Sampling Parameters of the K6/OCTAD-G (`GALAS') Sampler.

Sampling Rate	16384 MHz
Output Rate per port	4096 Msps
Sampling Quantization	3 bit
Output data Quantization	1 or 2 bit
Output Interface	10GBASE-SR
Number of Analog Inputs	2
Max. input signal frequency	16.4GHz

pico sec., which correspond 1 degree of rotation at 14 GHz. Thus there are no need to consider a significant coherence loss up to this frequency. The frequency response of input circuit indicted signal attenuation at higher frequency was 6dB at 14 GHz. This must be corrected by equalizer in practical use.

3. Frequency Comparison Experiment

Frequency comparison experiment with GALA-V system is under the preparation between NICT Headquarter in Tokyo and National Metrology Institute of Japan (NMIJ) in Tsukuba. Both institutes are independently developing optical frequency standards and their comparison is expected. The 1.6-m diameter antenna has been transported and placed at NMIJ in January 2014. Test experiments are to be conducted in the first half of 2014.

6. Summary

Wideband VLBI observation system named GALA-V is being developed by NICT. Observation frequency range of the Gala-V system is the same with that of VGOS specification. Thus joint observation with VGOS network is in the scope of the project. The GALA-V system uses fixed frequency allocation for observation. That frequency array was chosen by avoiding RFI and for good delay resolution function. Development of new wideband feed system for 34m antenna is in progress. RF-direct sampling technique is employed and being evaluated. Frequency comparison experiment is under the preparation between NICT Headquarter and NMIJ at Tsukuba in Japan.

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