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Development of Broadband VLBI System and its Application to T&F Transfer

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Abstract

NICT is developing a new broadband VLBI system, named GALA-V, for distant frequency comparison. Frequency of atomic standards connected to transportable small antennas are compared through broadband VLBI observations. Disadvantages of small antenna in sensitivity is compensated by ten times wider observation frequency, and by joint observation with large diameter antenna. Our broadband feed IGUANA-H(6.5-15GHz) and NINJA(3.5-15GHz) were developed for Cassegrain type Kashima 34m radio telescope by our original design. The system performance evaluation of the Gala-V system is being conducted at NICT (Koganei) - NMIJ (Tsukuba) baseline, where both institutes are keeping their own UTC time systems.

In addition to VLBI experiments by using small antennas installed at NICT (Koganei) and NMIJ (Tsukuba), VLBI experiments between the new VGOS 13m antenna at Ishioka of GSI and Kashima 34m antenna of NICT have been conducted for performance evaluation of our broadband GALA-V system. As the results, super broadband VLBI observation over 8GHz bandwidth, and coherent signal synthesis were successfully achieved, and sub-pico second group delay resolution was achieved for the first time in the world.

2. Technology Development of the Broadband VLBI System

All of currently available broadband feeds such as Eleven Feed[1] and QRFH[2] have wider beam width around 120 degrees, thus all of the radio telescopes of VGOS specifications uses special optics design so called 'ring focus'. Ring focus optics places the receiver at very close to the sub-reflector, thus broadband radio telescope had to be newly build as far as these feeds are used. We have developed new broadband feed prototype-1 named IGUANA-H and the second prototype NINJA, which have bream width around 34 deg. for Cassegrain optics Kashima 34m radio telescope(c.f. presentation by Ujihara et al., DBp.2.34 – "Development of Wideband Feed" in this IAU-GA). These feeds works at 6.5-15GHz and 3.5-15GHz, respectively (Fig. 2).

Due to difficulty of broadband polarizer, linear polarization signal is received by the feed. Then received signal is transferred from the telescope to observation room without frequency down conversion. Conventionally after bandpass filtering and frequency conversion, analog signal is quantized by sampler. In addition to this conventional method, we are investigating use of direct sampling technique.

Direct sampling technique samples the data at radio frequency, then signal at desired frequency band is output by digital filtering technology inside the sampler. This new technique is enabled by high speed sampler 'K6/GALAS', which has 16GHz sampling with 3 bit quantization (Fig. 3.). Some specification parameter of the K6/GALAS sampler is listed in Table 1.

Fig.2 NINJA(left) and IGUANA-H feed mounted on Kashima 34m antenna.

Fig.3 K6/GALAS used for direct sampling VLBI experiments.

Table 1. Specification Parameter of K6/GALAS

Sampling rate	16384MHz
Sampling quantization bit	3 bits
Number of Analog inputs	2
Max input frequency	16.4 GHz
Output quantization bit	1 or 2 bit
Number of Output	4 ports at maximum
Output Interface	10GBASE-SR
Output Data format	VDIF/VTP/UDP

4. Broadband VLBI Experiment with Ishioka VGOS station

Geospatial Information Authority (GSI) has constructed VGOS compliant new VLBI antenna at Ishioka city. The VGOS (VLBI2010 Global Observing System) is the next generation geodetic VLBI system promoted by the IVS. Our GALA-V system is designed to be compatible with the VGOS with a scope to enable joint observation with them. Ishioka 13m antenna is only one domestic counterpart for broadband VLBI observation with Kashima 34m in Japan. Both of

We have made the first broadband VLBI experiment with acquiring six 1GHz bandwidth data at 6-10GHz, 11GHz, and 13GHz. Fig. 6 displays the cross spectrum and synthesized delay resolution function of the 8GHz bandwidthThis is the first achievement in the world and its theoretical delay precision reaches 2.7 x 10-14 seconds. . Great advantage of direct sampling technique is that instrumental phase character and inter-band delay are not significant and quite stable, because the A/D conversion is performed at one for whole frequency band. Fig. 7 shows the delay observable of 1 second integration every over 700 seconds. Different color of plot (red, green, and blue) indicates delay data synthesized bandwidth of 4GHz, 6GHz and 8GHz, respectively. This Figure indicates the scattering become smaller as increasing the bandwidth with keeping systematic behavior unchanged. Table 2 shows the root-mean-square (RMS) of delay observable at 1 second integration along the systematic delay change. It shows the delay precision increases as the bandwidth gets wider. The systematic delay fluctuation can be interpreted as atmospheric delay. If this is true, this is the first detection of atmospheric effect by group delay observable with sub-pico second precision.

1. Introduction

Fig. 1 shows the concept of the GALA-V system. For comparison of atomic frequency standards by VLBI, GALA-V project uses transportable small diameter antennas to be placed at institutions of atomic clock developments. Since the signal to noise ratio (SNR) of VLBI observation depend on observation bandwidth and the products of sensitivities of the two radio telescopes involved in the observation (see Equation (1)), sufficient SNR for clock comparison between small diameter antennas is realized by broadband observation and joint observation with larger diameter antenna.

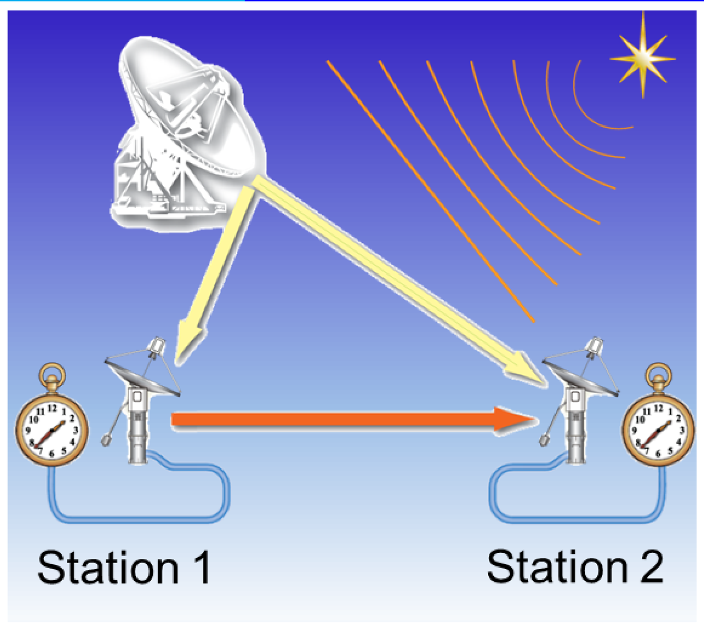

Fig.1 Concept of GALGA-V system for distant frequency comparison.

$$SNR \propto SD_1D_2\sqrt{\frac{\eta_1\eta_2}{T_{sys1}T_{sys2}}BT} \cdots (1)$$

D : Antenna Diameter Tsys : System Temperature η : Antenna Efficiency
B : Receiving Bandwidth [Hz] T : Integration Time [sec]

Original observation mode of Gala-V system is designed as acquiring four 1GHz bandwidth signals at 4.0GHz, 5.6GHz, 10.4GHz, and 13.6GHz by taking into account local RFI survey results and delay resolution function expected from the frequency allocation. The 'zero redundancy' array of frequency allocation enables fine delay resolution with minimum side lobes. Its effective bandwidth reaches to 3.8GHz, which is about 10 times wider than conventional geodetic VLBI observation..

3. Comparison between UTC[NICT]-UTC[NMIJ] with Gala-V

Fig. 4 shows the two small diameter (1.5m and 1.6m) antenna installed at NICT headquarter at Koganei and National Metrology Institute of Japan (NMIJ) at Tsukuba. These two antennas have broadband observation capability by using Quad Ridge Horn Antenna (QRHA), which is commercially available from ETS-Lindgren Company. For testing frequency comparison capability, UTC[NMIJ]–UTC[NICT] was measured by the GALA-V system with single channel 1GHz bandwidth VLBI observation at 8GHz and compared with GPS observation results and publication of UTC –UTC(k) by BIPM (Fig. 5). The plot indicated that VLBI measurement shows consistent result with that of GPS and that provide from BIPM. Since the bandwidth was limited 1GHz in this VLBI experiment, further improvement can be expected by fully broadband observation.

Fig. 4 Pictures of 3 radio telescopes of the GALA-V system. 1.6m antenna at NMIJ (top-left), 1.5m antenna at NICT/Koganei (top-right), and 34m radio telescope at NICT/Kashima(right).

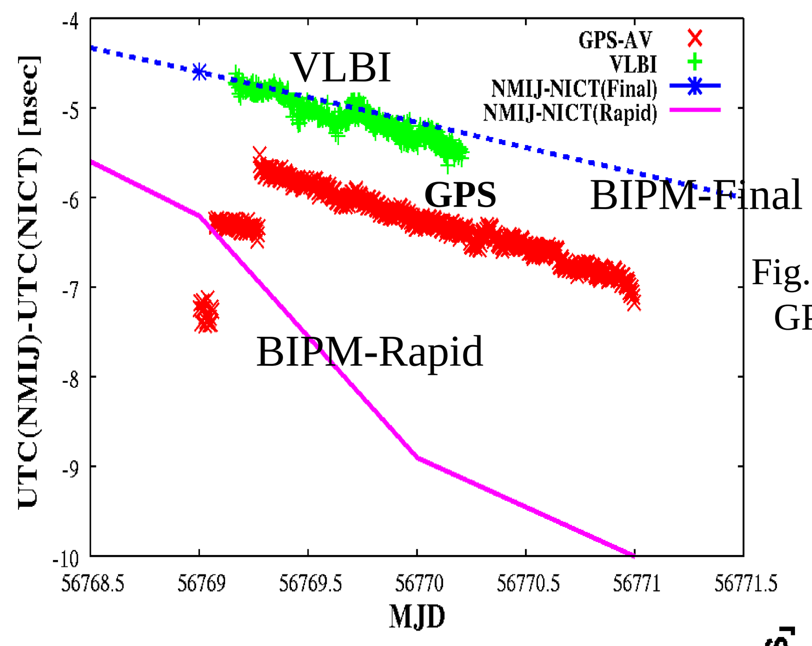

Fig.5. Comparison of UTC[NMIN]-UTC[NICT] with VLBI, GPS, and UTC(k) comparison published from BIPM.

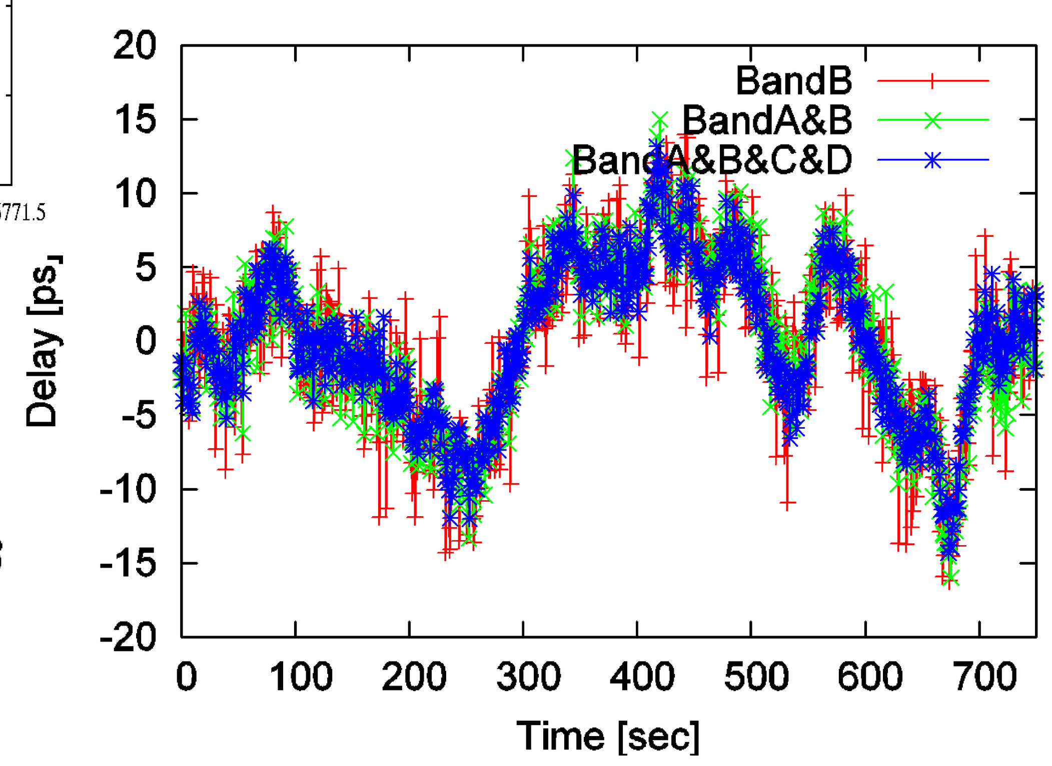

Fig.7. Delay observable obtained by Bandwidth synthesis at 1 second integration. Red, green, and blue marks are delay derived with 2GHz, 4GHz, and 8GHz bandwidth synthesis, respectively.

Table 2. Root-mean-square of delay observable at 1 second integration.

Bandwidth [GHz]	RMS [ps]
1	3.08
2	2.01
4	0.96
8	0.60

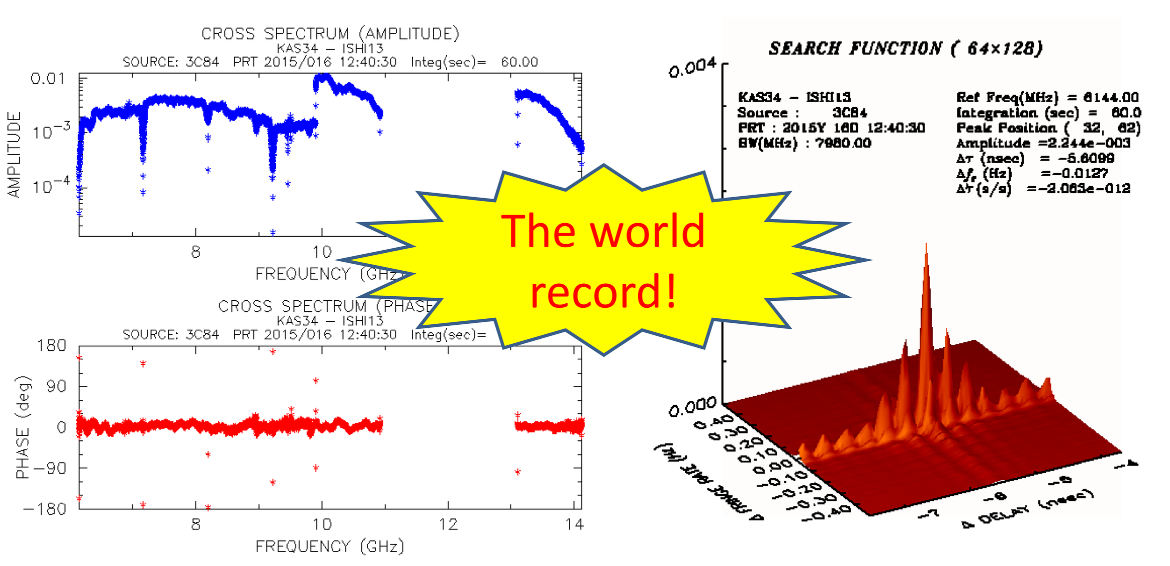

Fig.6. Cross Spectrum(left) and Delay resolution function(right) derived from 8GHz broadband bandwidth synthesis with 60 second integration. Instrumental inter- and intra-band phase character was compensated with signal from strong radio source. Its theoretical delay precision reaches to 27 femto-second.

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