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Broadband System from 3.2 GHz to 14.4 GHz at Kashima Space Technology Center

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We have been developing broadband system for time and frequency transfer by VLBI technique. Currently, two compact antennas (1.6 meter and 2.4 meter, so-called MARBLE) have been installed to Japanese time keeping institutes. One is installed to AIST in Tsukuba and other is to the headquarter of NICT in Tokyo. Since our MARBLEs are too small to get fringes, broadband receiving system of VGOS is required to get higher SNR and a large dish like Kashima 34 meter is required to obtain fringes with MARBLEs. Thus, we installed a broadband system including a new feed, so-called NINJA, to Kashima 34 meter. We report the progress of our development and recent results of broadband VLBI experiments in a frequency range of 3.2 GHz to 14 GHz.

Keywords: VLBI, VGOS

1 Introduction

National Institute of Information and Communications Technology (NICT) has been not only developing VLBI observation system as the IVS-TDC, but also maintenance and keep the Japanese time standard. Recently NICT, AIST and Tokyo university have been developing an optical-lattice clock for the next generation time standards and for the redefinition of "the Second". Thus, it is necessary to compare with the distant clocks of each countries over international baseline with several techniques. In case of two stations are close in a few hundreds kilometer, optical-fiber transmission is the best technique for the comparison. However distant stations comparison over thousand kilometer and inter-continent is needed some technique through space for example GPS, Two-Way Satellite Time and Frequency Transfer (TWSTFT) and VLBI.

With regards to the Time and Frequency transfer (T&F) by VLBI, the order of 10^{-16} in a few days is targeted. Since our two MARBLEs are quite small for VLBI, it is necessary to have a broad-band system and to make effective system such as a VLBI2010 Global Observing System (VGOS).

For the next generation of the geodetic VLBI, VGOS has been specified a fast moving antenna and broad-band receivers. Some antennas, which meet the VGOS requirements, have been constructed for example GGAO 12 m antenna and 18 m Westford in the United States, TWIN Radio Telescope Wettezell (TTW) in Germany, the RAEGE telescope at Yebes in Spain and at Santa Maria in Portugal, three VGOS antennas of QUAZAR network in Russia, one is in Sweden, in Finland and Ishioka telescope in Japan.

We, NICT/Kashima, has been also developing a broad-band system from 3.2 GHz to 14.4 GHz to our Kashima 34 meter antenna and two small and transportable antennas (see figure 1).

The broad-band project is so-called "GALA-V".

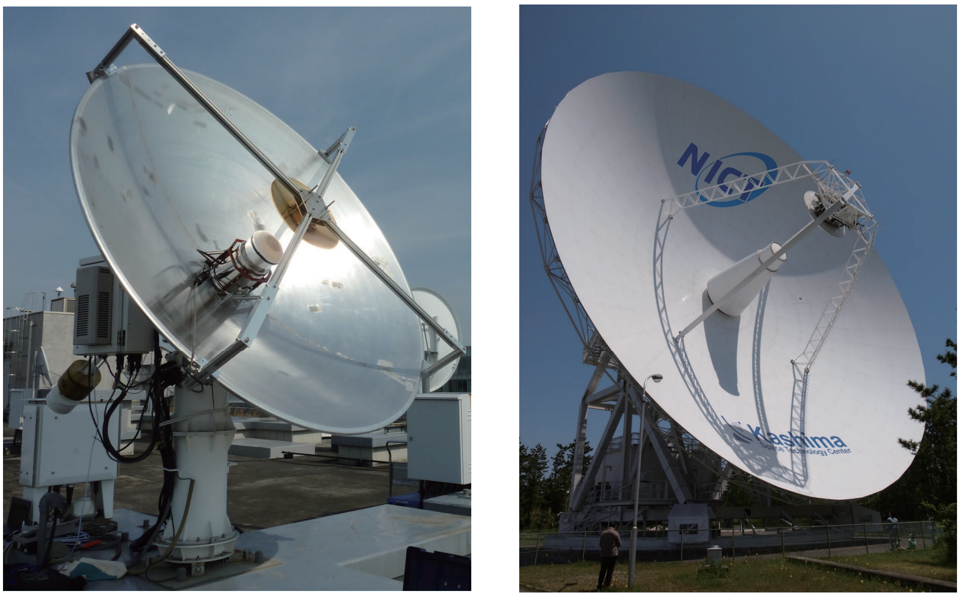

Fig. 1. Broadband compact antenna No.2 (MARBLE2) in Tokyo (left) and Kashima 34 meter in Ibaraki (right)

2 Development

The three stations have each broadband feed and a 16GHz sampling direct sampler K6/GALAS. Currently we have installed two type of broadband feed for Kashima 34m. Firstly IGUANA-H for 6.5 GHz to 15 GHz since December 2013 [2] and secondary NINJA, 3.2 GHz to 14.4 GHz (SEFD 1500 Jy) since July 2015. The modified NINJA feed 3-15GHz has been installed to MARBLE 2 (SEFD $\sim$5 kJy) in early 2016. MARBLE 1 is currently used QRHA of ETS Lindgren, but soon its feed and main dish will be replaced modified NINJA feed. The broadband feed of Kashima 34 meter radio telescope was specially designed to have a sharp beam pattern within 20 degree to illuminate the sub-reflector.

The direct sampler K6/GALAS[3] (see table 1 for the specification) has DBBC inside. Since deploying the K6/GALAS, the front-end system has become quite simple. Currently K6/GALAS has 2 ADCs, First IF inputs lower 8 GHz range and second IF inputs upper 8 GHz range, which will covers the whole frequency allocation of VGOS. Because RF signal is directly digitized without analog frequency conversion, the phase differences between the output channels are fixed at sampling stage. Thus, high precision delay can be derived with high stability by broadband bandwidth synthesis.

Frequency range	0.01 to 24 GHz
Number of analog input	2
Sampling rate	16384 or 12800 MHz
Quantization	3 bit
DBBC	1GHz bandwidth, 2 bit, 4 streams
10GbE protocol	VDIF / VTP/ UDP / IP

Table 1. Specfications of direct sampler K6/GALAS

3 The 24h VLBI experiment and bandwidth synthesis

We have carried out a series of geodetic VLBI experiments between Kashima 34 meter and two MARBLEs for several years step-by-step. Here we report a VLBI result on the day of 176, 2016, which has 1850 scans of four 1 GHz bandwidth (5.4, 6.5, 8.2 and 10.1 GHz) with observing 18 quasars for 46 hours.

At first we determined a template scan with strong source (we selected the quasar 3C84) from entire scans for wide bandwidth synthesis (WBWS)[1]. Secondarily, whole scans were compensated by the template scan (see left figure 2 for an example), then residual delay and delay rate were estimated by calculating a search function. Finally differential TEC were estimated, however two baseline lengths of this session were only 50 km and 100 km, we did not applied the TEC estimation. The delay error of single band and synthesized band, whose error was improved 14 times better than that of the single band of 5.4 GHz.

With regards to baseline analysis, the root-mean-square (RMS) of delay for 46 h VLBI became 35.1 ps and 34.4 ps, for the baseline of Kashima34-MARBLE1, and Kashima34-MARBLE2 respectively. Finally we could obtain the baseline result on MARBLE1-MARBLE2 by linear combination of the above two baseline results. Its RMS delay of baseline analysis was 36.4 ps, which is shown in right of figure 2.

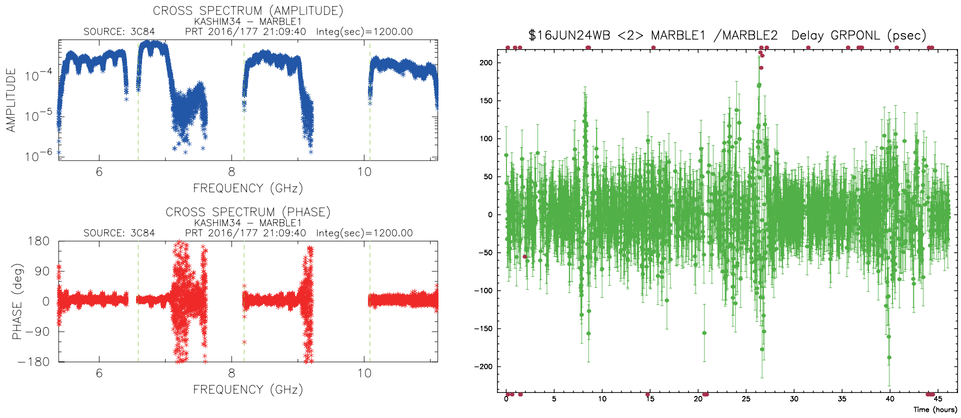

Fig. 2. Left: Cross-spectrum of the Kashima34-MARBLE1 baseline after compensated delay and the phase by the template scan. The flat phase means the bandwidth synthesis was successfully performed. Right: RMS delay of the analysis result of MARBLE1 to MARBLE2 baseline data computed by linear combination of two Kashima34 baselines results.

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