NICT Technology Development Center 2017+2018 Biennial Report

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Abstract The National Institute of Information and Communications Technology (NICT) is developing and testing VLBI technologies and conducts observations with this new equipment. This report gives an overview of the Technology Development Center (TDC) at NICT and summarizes recent activities.

1 NICT as IVS-TDC and Staff Members

The National Institute of Information and Communications Technology (NICT) publishes the newsletter "IVS NICT-TDC News (former IVS CRL-TDC News)" at least once a year in order to inform about the development of VLBI related technology as an IVS Technology Development Center. The newsletter is available at the following URL: `http://www2.nict.go.jp/sts/stmg/ivstdc/news-index.html`. Table 1 lists the staff members at NICT who are contributing to the Technology Development Center.

Table 1 Staff members of NICT TDC as of January 2017 (alphabetical).

HASEGAWA, Shingo	KAWAI, Eiji
MIYAUCHI, Yuka	SEKIDO, Mamoru
TAKEFUJI, Kazuhiro	TSUTSUMI, Masanori
UJIHARA, Hideki	

Kashima Space Technology Center, National Institute of Information and Communications Technology

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2 General Information

We have been developing a broadband VLBI system called GALA-V, which has to meet the VGOS (VLBI Global Observing System) requirements among others, and also upgrading Cassegrain optics antennas such as our 34-m radio telescope and compact telescopes for the project of Time and Frequency transfer.

3 The 2.4-m Diameter Compact Antenna Installed in Medicina for Time & Frequency Transfer by VLBI

In March 2018, the 2.4-m diameter compact telescope installed at NMIJ at Tsukuba was moved to Kashima so maintenance could be performed. Then, all instruments were packed and transferred to the Medicina observatory in Bologna in May 2018. We visited Bologna to install the compact antenna in summer 2018. After we spent one week, the antenna was successfully installed, and we got first fringes between Ishioka and Medicina during our visit (Figure 1).

4 Broadband VLBI on Italy and Japan Baseline

We have conducted VLBI experiments for optical clock comparison on an Italy–Japan intercontinental baseline. A reference signal generated by the Yb optical lattice clock at INRIM in Torino is provided to Medicina by a stabilized optical fiber link. The

Fig. 1 Memorial picture when the 2.4-m diameter compact telescope was successfully installed at Medicina observatory.

Sr lattice clock has been operated at the NICT headquarters. These two optical lattice clock signals were compared by a series of VLBI experiments via VLBI network observations with transportable 2.4-m diameter broadband VLBI stations at the Medicina radio astronomy observatory of INAF in Italy and the NICT headquarters at Koganei, Japan and the 34-m radio telescope at Kashima. Hydrogen masers are used as reference signal for the VLBI observations, and the behavior of these masers as a fly-wheel for maintaining clocks is monitored at each end with optical clocks, which were operated intermittently. The VLBI link of the frequency transfer will be compared with the GPS link as an alternative technique.

Since October 2018, we have conducted standard geodetic VLBI experiments, where multiple radio sources in different parts of the sky are observed alternately. We chose about 20 compact quasars, whose flux densities are mostly over 1 Jy, from the radio catalogs in a single session. NINJA feeds originally developed for broadband, which are capable of observing in a 3.2 to 14.4 GHz frequency range, are mounted at the two 2.4-m diameter VLBI antennas and the Kashima 34-m antenna. A single linear receiver is equipped at these small VLBI stations and dual linear polarization at the 34-m VLBI station.

The initial observation was made at the 5.5 GHz, 8.0 GHz, 10.0 GHz, and 12.8 GHz radio frequencies with 1-GHz bandwidth each. A high speed RF-direct sampling technique, which digitizes the radio signal at 16 GHz sampling, enables stable group delay measurements in a broad frequency range. About 60 TB of observation data at Medicina was transferred on average at 5 Gbps to Kashima in two days for each session via high speed research networks by using jive5ab. Over the next four days, we correlated a total of 240 TB with the GICO3 software correlator. For post processing, two linear polarization datasets (V-V and H-V) are combined with compensation for the delay and the phase differences (shown in the left panel of Figure 2). Signals over the broad frequency range are synthesized by wideband bandwidth synthesis with correction of the ionospheric delay. The right panel of Figure 2 shows the measured ΔTEC effect during the session.

5 Holographic Measurement of Kashima 34-m RT by Applying VLBI Technology

Holographic measurements are performed by applying the correlation between a reference antenna and a target antenna. Normally the direction of the reference antenna is toward a stationary orbit satellite, and the target antenna drives in a zigzag motion toward the satellite so that it covers a beam pattern map of the target antenna. The two dimensional beam pattern after correlation has a Fourier relationship between the illumination pattern and the displacement distribution of the target surface. Thus, a wider angle observation makes a finer result.

The repair work of the main mirror of the Kashima 34-meter telescope in summer 2018 was anticipated to shift the main mirror and degrade the sensitivity. Actually, our staff reported a change of a few cm during the repair work. We developed the holographic measurement with applying the VLBI technology (see Figure 3) and performed it before and after the repair work. Data reduction of the holographic measurement was performed as follows:

1. Acquiring data by K5/VSSP32 at 16-Msps, 8-bits.
2. Correlating the 8-bit data by GICO3 and outputting the data every 10 ms.
3. By comparing the antenna log and the correlation output, representing the correlation output in the Az and El domain.
4. Performing a two dimensional Fourier transform with rough removal of the phase offset and the phase slope.

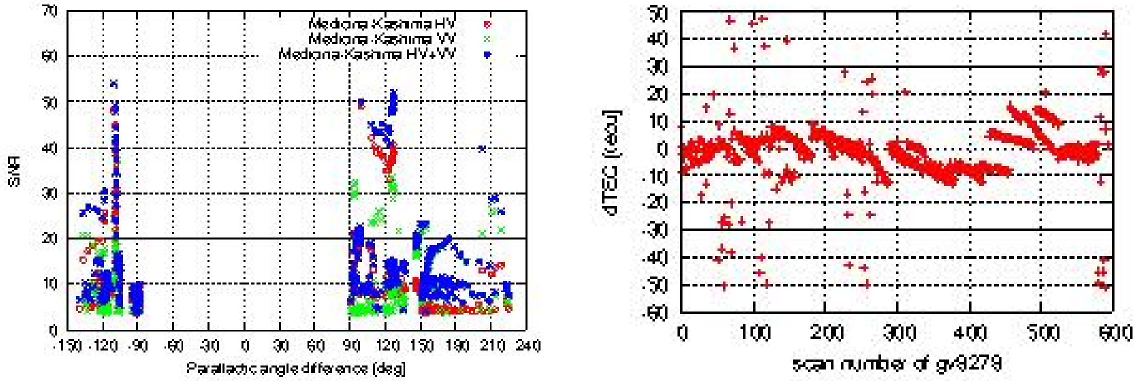

Fig. 2 Left: red circles show the Hpol-Vpol correlation results for the Kashima and Medicina baseline, and green crosses are for the Vpol-Vpol results. After two polarization pairs were synthesized, the SNRs shown as blue asterisks improved. Right: ionospheric effect by wide bandwidth synthesis clearly appears with a large variation on the Italy and Japan baseline in a 30-hour session.

5. Performing the least squares method to remove the phase offset accurately.
6. Calculating the displacement value at each bolt position on the antenna surface.
7. Let's adjust the surface!

Figure 4 shows the measurement system. Here, signals from two antennas are transferred to the observation room, and we record the data by K5/VSSP32 after a single down-conversion is done. After the repair work was completed, we iteratively adjusted the main surface based on the holographic measurements. The results are shown in Figures 5 and 6. The RMS just after the repair work was completed was 1.5 mm, and the RMS after the adjustment of the surface was 0.3 mm.

Fig. 3 Reference antenna and Kashima 34-m RT during the holographic measurement.

6 Wideband Feed Development

6.1 Kashima 34-m Antenna

The NINJA feed for the 34-m antenna was replaced by a newly developed feed. The distinguishing feature of this feed is shorter length and less weight than the previous one (Figure 7). Before replacing the old feed, the far-field patterns of the new one were measured by a near field scanner in the radio shielded room at METLAB at Kyoto University. Also, the aperture efficiency after installation at the 34-m RT is 30–40% and nearly flat at upper frequencies with ripples over 3.2–14.4 GHz. The ripples will be improved by reducing the return loss of the OMT and anti-reflection coating of the lenses in future development.

6.2 MARBLEs: The 2.4-m Diameter Antenna

MARBLE1 was moved to the Medicina radio observatory in Italy for intensive experiments of VLBI T&F transfer with Japan. Both MARBLE1 and MARBLE2 were refurbished with rigid and light weight CFRP pipes as a pillar to keep their mirrors at $\pm$1mm ac-

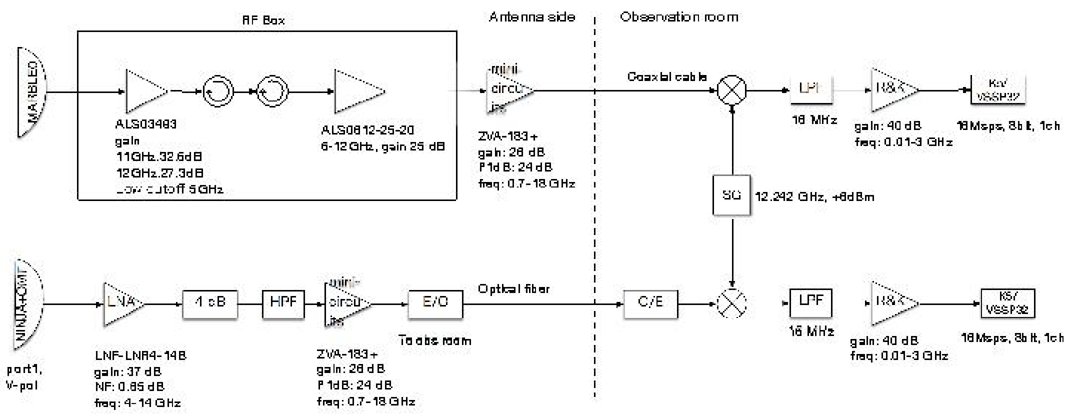

Fig. 4 System diagram of the holography measurement.

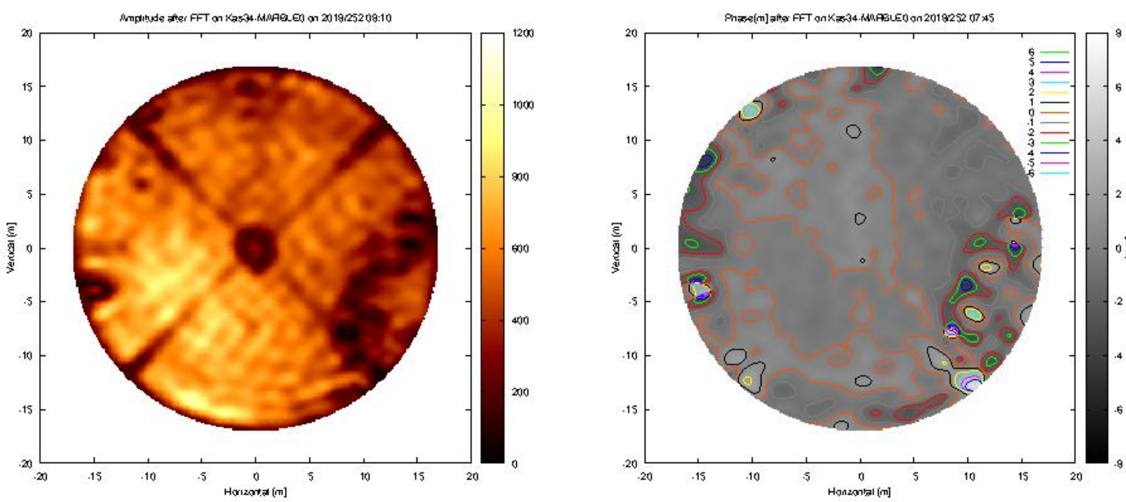

Fig. 5 Left: obtained illumination pattern. The cross in the figure was caused by four pillars that support the secondary mirror. Right: displacement distribution (right) of the Kashima 34-meter telescope just after the repair work was completed. Some messy regions due to the repair work and the 30 years of aging can be found in both figures.

curacy, and the NINJA feeds were replaced with new OMTs and lenses (Figure 8). RF over the fiber system of MARBLE1 was also replaced to improve stability before shipment to Bologna in May 2018.

6.3 Ortho Mode Transducer (OMT)

Extremely strong RFI under 3 GHz had made an intermodulated noise and pushed up the noise temperature of our Gala-V system. Thus, dedicated OMTs with sharpened skirts under 3.2 GHz to cut such RFI were developed, and they replaced the previous OMTs of NINJA feeds in the 34-m antenna and the MARBLEs.

7 Future Development Plans

Development of a new water vapor measurement system with a 20–60 GHz wideband feed and preliminary research for a 1.5–15.5 GHz wideband second focus feed for the BRAND project were started.

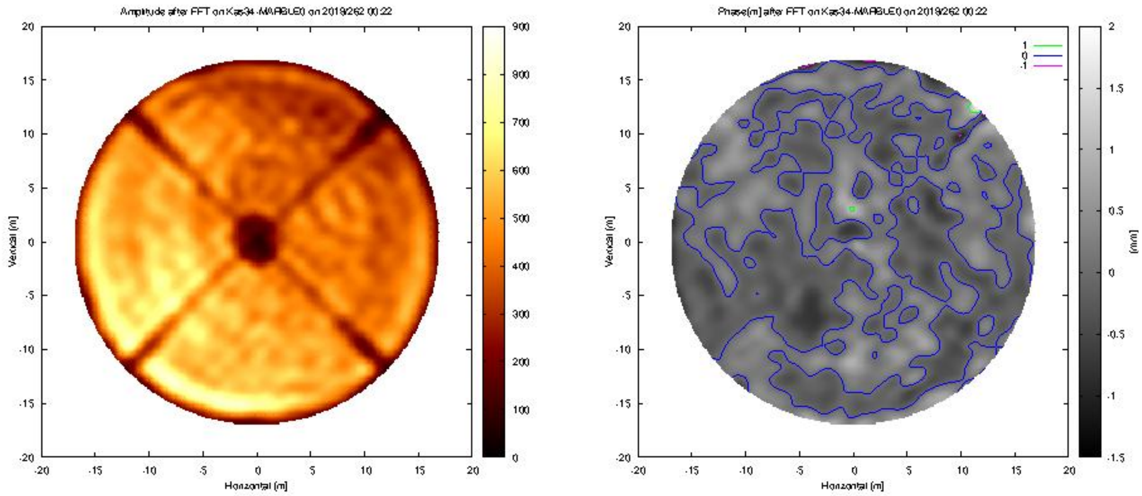

Fig. 6 Same as Figure 5 but after the careful surface adjustment was completed.

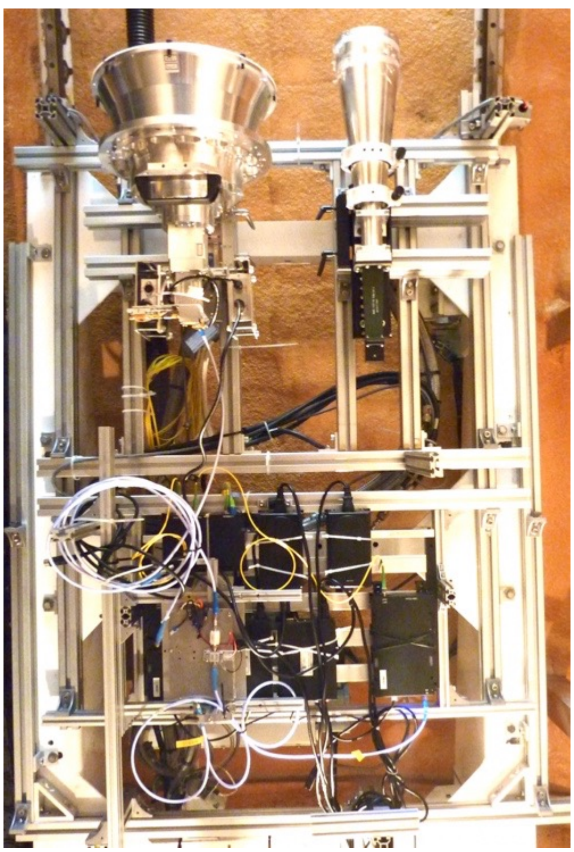

Fig. 7 The new compact NINJA feed installed on the left stage of the receiver carriage in the feed cone of the Kashima 34-m antenna. IGUANA-H is placed on the right.

Fig. 8 Refurbished MARBLE1 at Kashima before shipment to Bologna.