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MARBLE (Multiple Antenna Radio-interferometry for Baseline Length Evaluation): Development of a Compact VLBI System for Calibrating GNSS and Electronic Distance Measurement Devices

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Abstract

We are developing a compact VLBI system with a 1.6-m diameter aperture dish in order to provide reference baseline lengths for calibration. The reference baselines are used to validate surveying instruments such as GPS and EDM and is maintained by the Geospatial Information Authority of Japan (GSI). The compact VLBI system will be installed at both ends of the reference baseline. Since the system is not sensitive enough to detect fringes between the two small dishes, we have designed a new observation concept including one large dish station. We can detect two group delays between each compact VLBI system and the large dish station based on conventional VLBI measurement. A group delay between the two compact dishes can be indirectly calculated using a simple equation. We named the idea "Multiple Antenna Radio-interferometry for Baseline Length Evaluation", or MARBLE system. The compact VLBI system is easy transportable and consists of the compact dish, a new wide-band front-end system, azimuth and elevation drive units, an IF down-converter unit, an antenna control unit (ACU), a counterweight, and a monument pillar. Each drive unit is equipped with a zero-backlash harmonic drive gearing component. A monument pillar is designed to mount typical geodetic GNSS antennas easily and an offset between the GNSS antenna reference point. The location of the azimuth-elevation crossing point of the VLBI system is precisely determined with an uncertainty of less than 0.2 mm. We have carried out seven geodetic VLBI experiments on the Kashima-Tsukuba baseline (about 54 km) using the two prototypes of the compact VLBI system between December 2009 and December 2010. The average baseline length and repeatability of the experiments is 54184874.0 $\pm$ 2.4 mm. The results are well consistent with those obtained by GPS measurements. In addition, we are now planning to use the compact VLBI system for precise time and frequency comparison between separated locations.

1. Introduction

The National Institute of Information and Communications Technology (NICT) has been working on the development of compact VLBI (Very Long Baseline Interferometry) systems and analysis technologies in the framework for the second midterm plan which began in fiscal year 2006. At the NICT, a system which combines all these components is called MARBLE (Multiple Antenna Radio-interferometer for Baseline Length Evaluation). The NICT is carrying out the development of the MARBLE system based on a research collaboration with the GSI of Japan. The GSI has the responsibility to calibrate and maintain a 10-km reference baseline for validating surveying instruments such as GPS (Global Positioning System) and EDM (electro-optical distance measurement). We are developing a compact VLBI system with a 1.6-m diameter aperture dish to certify the length of that reference baseline [1]. The scope of applying the MARBLE system is not only limited to the reference baseline lengths for calibration validation but enables also geodetic VLBI at locations where conventional VLBI systems have not been deployed so far. In addition, the NICT has considered the MARBLE system as a technology for realizing time and frequency (T&F) transfer for maintaining the precision of standard time systems by taking advantage of its portability and high precision characteristics. This paper provides results of geodetic experiments using the MARBLE system, as well as future development based on the "VLBI2010" concept, proposed by the International VLBI Service for Geodesy and Astrometry (IVS) as the next generation of VLBI technology.

2. Validation of Reference Baseline Lengths for Calibration and VLBI Measurement Technologies

The GSI has the responsibility to calibrate and validate survey instruments such as GPS receivers and EDM used by surveying companies. The facility which carries out this validation is called a "reference baseline lengths for calibration". It is located along a cycling road (built on leftover tracks of the former Tsukuba Tetsudo Tsukuba Line) of about 10 km in length located approximately 4 km east of the GSI headquarters in Tsukuba. Along the baseline, pillar monuments made of stainless steel are installed. To guarantee the quality of validation, the baseline length has to be evaluated routinely. In addition, GSI compares an operational EDM equipment and iodine-stabilized He-Ne laser wavelength standards in order to keep its traceability of length to a national standard maintained by the National Metrology Institute of Japan (NMIJ) and the National Institute of Advanced Industrial Science and Technology (AIST). However, since it is too long to get a line of sight from one end to the other end by EDM at the actual reference baseline, calibration works at present are only performed at the shorter baseline instead of a measurement of 10 km. Geodetic VLBI technique can give an independent measurement to examine the baseline with the accuracy of a few millimeters using the hydrogen-maser. Moreover, the hydrogen-maser frequency standard can be considered as the traceable technique to the national standard. Thus, we started to develop a compact VLBI system with a 1.6-m diameter aperture antenna in order to measure the accurate length of the reference baseline.

3. MARBLE Concept and Compact VLBI System Development

3.1. MARBLE System

We have started the development of compact VLBI systems specialized for geodetic purposes. The compact antenna is too insensitive to detect fringes between both stations. Therefore, we have designed a new observation concept by including one large-antenna station into observation networks and we have evaluated an availability of the concept. We refer to this method as the MARBLE concept and the schematic image of the new concept is shown in Figure 1 (see the previous paper in detail). As shown in Figure 1, compact VLBI systems are installed at both ends of the reference baseline lengths for calibration. Here, X and Y denote two compact VLBI stations at both ends of the baseline. In addition, one large antenna such as the NICT Kashima 34-m or the GSI Tsukuba 32-m, is added into the observation network (station R). We can detect two group delays between each compact antenna and the large one based on conventional VLBI measurement. A group delay XY between the two compact antennas can be indirectly calculated using a simple equation as shown in Figure 1. RX and RY are two group delays obtained in a conventional way. Here, in order to obtain the baseline length with 2 mm accuracy, each group delay of baseline RX and RY is determined within comparable or superior accuracy. The MARBLE system determines the integrated system including the observation network composed of a large antenna and compact antennas and its new analysis concept.

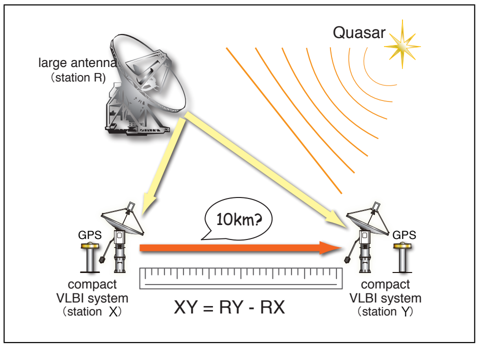

Figure 1. Schematic image of the MARBLE concept for the reference baseline validation.

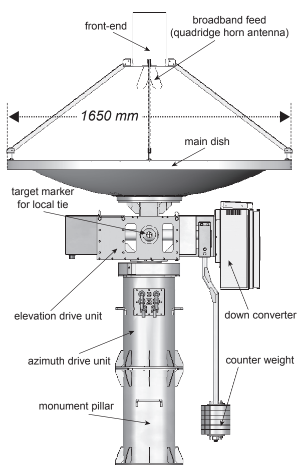

Figure 2. Schematic image of the MARBLE compact VLBI system.

Figure 3. Installation of a first prototype of the compact VLBI system on the top of the 34-m antenna building on December 9, 2008 at Kashima.

3.2. Compact VLBI System

Figure 2 shows a conceptual diagram of the first prototype. It consists of a 1.6-m diameter aperture antenna with a broadband feed, a drive unit of Az/El-mount type, an IF down-converter unit, an antenna control unit (ACU), a counterweight, and a monument pillar. Each drive unit is equipped with a zero-backlash harmonic drive gearing component. The monument pillar is designed to install typical geodetic GNSS antennas easily and an offset between a GNSS antenna reference point. A location of the azimuth-elevation crossing point of the VLBI system is precisely co-located within less than 0.2 mm of uncertainty. The antenna and mount can be dissembled into many parts avoiding the need for heavy machinery in approximately half a day using a tripod crane as shown in Figure 3. In the fiscal year 2008 we developed the second prototype of the system. By halfway through fiscal year 2009, the first prototype was installed at the NICT Kashima Space Research Center while the second one was installed at the GSI, and both were set-up to carry out the first verification tests (see Figure 4).

Figure 4. Station location.

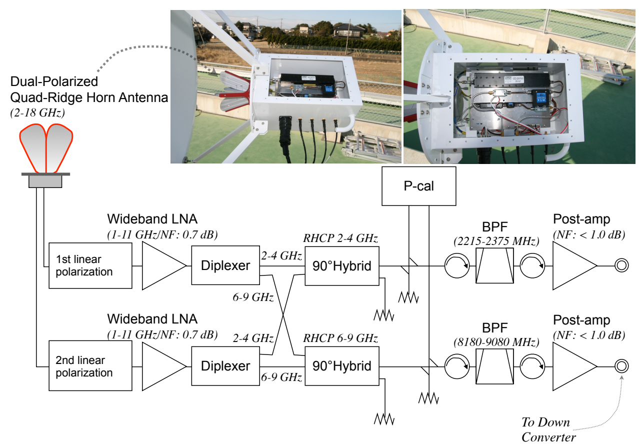

Figure 5. The new front-end system for the MARBLE compact VLBI system.

We developed a new front-end system using a broadband dual-polarized quad-ridge horn antenna (type 3164-05 ranging 2-18 GHz) made by ETS-Lindgren^{TM}. A block diagram of the new front-end system is shown in Figure 5. At the back of the feed, there is a front-end receiver with wide-band LNAs which can amplify up to 11 GHz. The front-end receiver also plays the roles of a polarizer and frequency discriminator. At present, the receiver is only set-up for S and X bands.

However, by replacing RF filters and other RF components, it will be able to receive arbitrary frequency bands between 2 and 11 GHz. As a test of this frontend system, on February 12, 2009, the first fringe detection was successfully completed using the first prototype and the Kashima 34-m antenna using the latest cutting edge "ADS3000+" A/D sampler. It operated at a sampling rate of 4096 Msps and was equipped with a high speed FPGA function, confirming its functionality as a VLBI. This allowed for the preparation of following geodetic experiments.

4. MARBLE System Geodetic Observation Results

We have carried out VLBI experiments on the Kashima-Tsukuba baseline (about 54 km) using the two prototypes of the compact VLBI system during December 2009 - December 2010. On December 24, 2009, the first 24 hour VLBI test used four stations; two prototypes of the compact VLBI system, the Tsukuba 32-m station and the Kashima 34-m station, was carried out. The formal error of the approximately 54 km of baseline between the two prototypes at Kashima and at Tsukuba was 2.7 mm. As of the end of 2010, five VLBI experiments have been successfully carried out. In addition, the monument pillar for the second prototype has a mechanism which allows for sliding of 20 mm in the horizontal direction. If this slider is intentionally displaced, the station position displacement detection can also be used as a precision evaluation item. The open square (VLBI) and open circles (GPS) in Figure 6 denote the results which the monument was displaced using this slide mechanism. The averaged baseline length and repeatability of the five experiments is 54184874.0 $\pm$ 2.4 mm which is well consistent with those obtained using GPS processing. In fact, the dual-frequency (S/X bands) processing for ionospheric delay compensation has not yet been carried out in these analysis results. In the same manner, for the results in Figure 6 for which ionosphere compensation has been also carried out, the RMS value was nearly 50% rather worse yielding a precision of 4.7 mm. The cause of this is still unknown. Since the effect of ionospheric delay error is somewhat canceled in the procedure of the MARBLE concept, it is possible to overestimate or to underestimate the effect. A further investigation about this issue needs to take place.

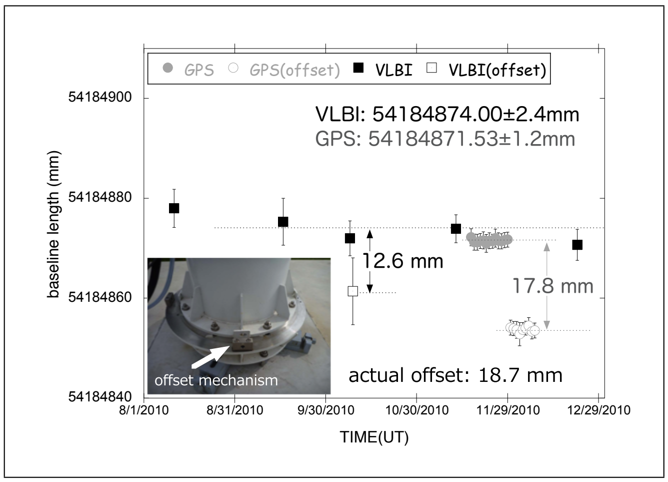

Figure 6. Results of geodetic experiments.

Using the slide mechanism, a maximum displacement of 18.7 mm can be introduced to the direction of the baseline between Kashima and Tsukuba. The displacement was set to 10.5 mm w.r.t. the results of October 8 and 13.7 mm when compared to the average value of the above three analyses, which are slightly too small. However, these results were well within the formal errors. It is necessary to carry out similar experiments multiple times in the future to investigate the details.

5. Conclusions and the Future of Compact VLBI Systems

We are developing a compact VLBI system with a 1.6-m diameter aperture antenna in order to provide reference baseline lengths for GPS and EDM calibration. The results of geodetic experiments imply millimeter level baseline determination is available using our compact VLBI system. The results are well consistent with those obtained by GPS measurements. In addition, we are now planning to use the compact VLBI system for precise time and frequency comparison between separated locations.

References

[1] Ichikawa R., A. Ishii, H. Takiguchi, H. Kuboki, M. Kimura, J. Nakajima, Y. Koyama, T. Kondo, M. Machida, S. Kurihara, K. Kokado, and S. Matsuzaka, Development of a Compact VLBI System for Providing over 10-km Baseline Calibration, "Measuring The Future", The 5th IVS General Meeting Proceedings (ed. by Finkelstein A, Behrend D), 2008, pp. 400-404, 2008.