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Current Status of the Development of a Transportable and Compact VLBI System by NICT and GSI

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Abstract

MARBLE (Multiple Antenna Radio-interferometer for Baseline Length Evaluation) is under development by NICT and GSI. The main part of MARBLE is a transportable VLBI system with a compact antenna. The aim of this system is to provide precise baseline length over about ~10 km for calibrating baselines. The calibration baselines are used to check and validate surveying instruments such as GPS receiver and EDM (Electro-optical Distance Meter). It is necessary to examine the calibration baselines regularly to keep the quality of the validation. The VLBI technique can examine and evaluate the calibration baselines.

On the other hand, the following roles are expected of a compact VLBI antenna in the VLBI2010 project. In order to achieve the challenging measurement precision of VLBI2010, it is well known that it is necessary to deal with the problem of thermal and gravitational deformation of the antenna. One promising approach may be connected-element interferometry between a compact antenna and a VLBI2010 antenna. By measuring repeatedly the baseline between the small stable antenna and the VLBI2010 antenna, the deformation of the primary antenna can be measured and the thermal and gravitational models of the primary antenna will be able to be constructed.

We made two prototypes of a transportable and compact VLBI system from 2007 to 2009. We performed VLBI experiments using these prototypes and got a baseline length between the two prototypes. The formal error of the measured baseline length was 2.7 mm. We expect that the baseline length error will be reduced by using a high-speed A/D sampler.

1. Introduction

We are developing a transportable and compact VLBI system. One of the purposes of the development is to measure accurately the baseline length of about 10 km. The Geospatial Information Authority of Japan (former Geographical Survey Institute, GSI) has a calibration baseline of 10 km to calibrate and validate surveying instruments for public purposes. These surveying instruments are GPS receiver and EDM (Electro-optical Distance Meter). To keep the quality of the calibration, the calibration baseline has to be examined regularly. However, the calibration baseline has been examined only by GPS up to now. Since this approach does not account for possible systematic errors, the examination by an independent technique is required. The VLBI technique can give an independent measurement of the calibration baseline in order to determine the systematic errors.

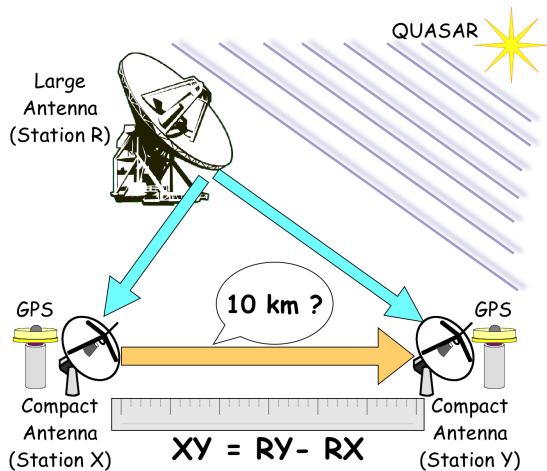


Figure 1. Measurement concept of MARBLE (Multiple Antenna Radio interferometer for Baseline Length Evaluation).

To achieve our goal, we made the following ideas. The geodetic VLBI system consists of a pair of compact VLBI stations with small antennas and a reference VLBI station with a large aperture antenna (Figure 1). The two small VLBI antennas are placed about 10 km apart. We can obtain the time delay between the small antennas by the time delays between the large antenna and each small antenna, even if we do not obtain the delay time between the small antennas directly. The baseline length of 10 km can be estimated by means of the indirect time delay. One of the advantages of this concept is not to have to get the time delay between the small antennas. Another advantage is that the comparison between the VLBI measurement and the GPS measurement is easy, because we only compare the reference point of a small VLBI antenna with the reference point of the GPS antenna. We do not need to compare the reference point of a large VLBI antenna with the GPS reference point. We call this idea ‘**M**ultiple **A**ntenna **R**adio-interferometer for **B**aseline **L**ength **E**valuation (MARBLE)’.

2. Compact VLBI System

The compact VLBI system is the core equipment of the MARBLE system as explained in the previous section. To perform measurements at several calibration baselines in Japan, one of the important requirements for the VLBI system is transportability. We made two prototypes of transportable and compact VLBI systems from 2007 to 2009. The VLBI systems consist of a small aperture antenna with drive unit of Az/EI-mount type (Figure 2), a receiver on ambient temperature, the K5 VLBI system [1, 2], and a frequency standard, among other parts. In the following, we describe details of the prototypes.

2.1. Small Antenna and Mount

The type of antenna is a front-fed paraboloid. The diameters of the reflectors are 1.65 m and 1.5 m for the first and second prototype respectively. The two reflectors have the same F/D of 0.45. At the focal point of the reflector, a wide-band feed (Quad-ridge horn antenna [3]) is placed. 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 polarizer and frequency discriminator. At present, the receiver is only for S and X bands [4]. However, by replacing RF filters and other RF components, it will be able to receive the frequency bands from 2 to 11 GHz.

The antenna and mount can be disassembled into many parts avoiding the need for heavy machinery. This feature is for transportability. For an easy comparison of the VLBI measurement

with the GPS measurement, the antenna has the following features: The compact VLBI antenna can host a GPS antenna on top of the El drive-unit, on top of the Az drive-unit, and on top of the base pillar. The antenna can also mount a target mirror for surveying at the azimuth-elevation intersection point which is the reference point of the geodetic VLBI measurement.

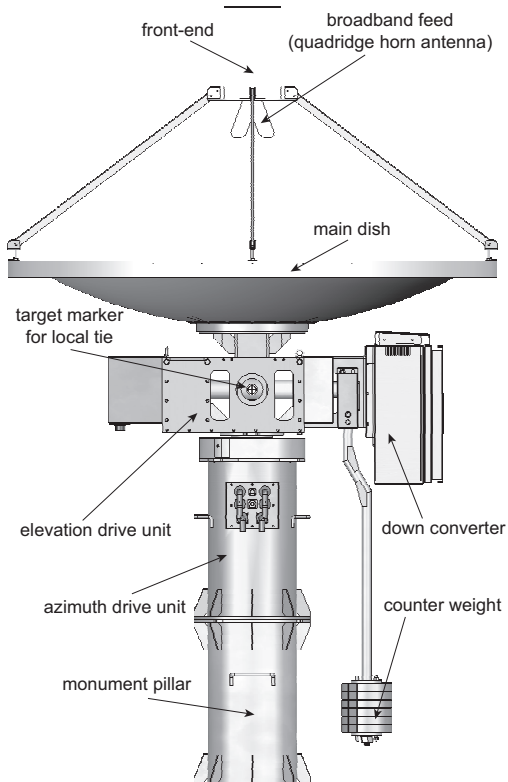


Figure 2. Schematic image of the antenna of the MARBLE system.

2.2. Frequency Standards

Transportability is required for the frequency standard of the compact VLBI system as well as the antenna. However, a conventional hydrogen maser frequency standard is unsuitable for transportation.

The frequency standard that we are going to use is a laser-pumped Cs gas-cell frequency standard (hereafter, we call it ‘Cs gas-cell oscillator’) [5]. The size and weight of the oscillator is roughly equal to a desktop PC. Its stability lies between that of a hydrogen maser frequency standard and a Cs beam type frequency standard. It is good enough to keep coherence for VLBI observation at the frequency of 8 GHz. Moreover, we confirmed the Cs-gas cell oscillator on geodetic VLBI using the Koganei 11-m antenna and the Kashima 34-m antenna [6].

Another option for the frequency standard system is the radio frequency transfer using optical fiber [7]. The development purpose of this system is a comparison of optical frequency standards which have much higher frequency stability than that of conventional microwave frequency standards. Therefore, this system can transmit the radio frequency from the hydrogen maser oscillator without degradation of stability. The only disadvantage of the system is that it requires dark fibers.

2.3. Applications

This compact and transportable VLBI system can be applied to various observations. For instance, it can be used for a comparison of VLBI time and frequency [8]. Only one VLBI station with a large antenna is needed for this purpose. By bringing a compact VLBI station with small antenna, time and frequency comparison is possible anywhere.

In the VLBI2010 project, it is expected that the compact VLBI station with small antenna can be used for gravity and thermal deformation model construction of a large VLBI antenna [9]. By repeating geodetic VLBI measurements using a large antenna and a small stable antenna placed near the large antenna, we will be able to model the deformation of the large antenna.

3. Performance Tests of the Prototypes

To test the performance of the prototypes, we installed the first prototype near the Kashima 34-m antenna in NICT in December 2008 and the second prototype near the Tsukuba VLBI station (32-m antenna) at GSI in October 2009. Before setting up the second prototype, we performed general geodetic VLBI experiment of 24 hours using the first prototype. In the experiment, we also used the Tsukuba VLBI station and the Kashima 11-m station. The hydrogen maser oscillators were used as frequency standards at each station, the observed bands were S and X band, and the total recording data rate was 512 Mbps in the experiment. As a result of the experiment, we successfully obtained fringes over the 24 hours and could estimate the baseline length between the Kashima 11-m station and the first prototype to about 200 m (Table 1). The formal error of the measured baseline length was 2.4 mm.

After installation of the second prototype, we carried out another VLBI experiment of 24 hours using the two prototypes and the Tsukuba VLBI station. The frequency standards, observed band, and the total recording rate were the same as in the previous experiment. We could estimate the baseline length between the two prototypes to be about 54 km (Table 1). The formal error of the estimated baseline length was 2.7 mm. However, in this experiment, there were many outliers of several tens of nsec in the delay residuals. We could not find the origin of the failure, but we expect that the cause is the failure of bandwidth synthesis. Since the influence was large in S band, we did not include the time delays from S band in the analysis. Though there was such a problem, the baseline length could be measured by using the two prototypes. This result is evidence that these prototypes are usable for geodetic VLBI. Moreover, there is room for making the observation data rate higher. The higher observation data rate will bring a smaller measurement error for the baseline length.

Table 1. Results of experiments using the MARBLE system(s).

date	baseline	WRMS	baseline	formal error* ¹		
		residual (psec)	length* ¹ (mm)	u-d	e-w	n-s
2009. 6.25	R* ² -B* ³	58	193845.7 ± 2.4	6.2	2.7	3.5
2009.12.24	B* ³ -C* ⁴	18	54184878.6 ± 2.7	19.5	2.7	2.6

*1 The errors represent 1 sigma of the formal errors.

*2 R : Kashima 11-m station

*3 B : first prototype of MARBLE

*4 C : second prototype of MARBLE

4. Conclusion and Outlook

We made two prototypes of a compact and transportable VLBI system. We performed geodetic VLBI experiments using these prototypes. The formal errors of the baseline length estimation are about 2 to 3 mm. From the result, we confirm that these prototypes can be used on geodetic VLBI. There is room for improvement of the error of the measurement. If we identify the cause, and it is possible to solve it, the measurement error will be decreased. On the other hand, now the

higher speed A/D sampler (ADS3000+) is available [10]. The measurement error will be decreased by using ADS3000+ also. To obtain a higher measurement precision than the current precision, we continue the development. We plan to make another prototype. We will review the antenna design and the receiver design, and we will make a more sensitive VLBI station.

This compact and transportable VLBI system can be applied to various observations. We are also planning to apply our prototype to time and frequency comparison experiments in 2010.

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