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II. OVERVIEW OF THE EXPERIMENT SYSTEM

II.1 THE MAIN VLBI STATION AT KASHIMA

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ABSTRACT

The Western Pacific VLBI Network was mainly organized by the VLBI stations of Communications Research Laboratory (CRL), Kashima, Marcus Island and Minamidaito Island, and Shanghai of China. The 34 m antenna built at CRL's Kashima Space Research Center (KSRC) in 1988 has been used as the main station of the Western Pacific VLBI Network. This antenna was constructed as one of the largest antennas in Japan and its main purpose is precise geodesy. It has many advanced functions for this purpose but was also designed for multipurpose observations. It is therefore also the main tool in precise space and time measurement projects, such as the earth rotation measurement VLBI, millisecond pulsars timing observations, and radio astronomical observations.

Keywords: VLBI (Very Long Baseline Interferometry), geodesy, plate motion, antenna

1. Introduction

The Communications Research Laboratory (CRL) has, since the middle of 1970s, been engaged in a study of Very Long Baseline Interferometry (VLBI) and international and domestic VLBI observations. The main observation tool for this study was the 26 m antenna which was built in 1967. This antenna was built for the experiments of satellite communications using 4/6 GHz bands, but was modified for VLBI experiments such as the US-Japan VLBI experiments for the NASA's Crustal Dynamics Project. Many remarkable results in the field of space geodesy(1)-(4) were obtained using this antenna but the research fields were expanded by constructing a new high-performance antenna (higher sensitivity and higher receiving bands) at Kashima Space Research Center.

A 34 m antenna made by TIW company in USA was introduced in 1987, and its construction was completed in 1988. The main project using this antenna is the "Western Pacific VLBI Network

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*National Astronomical Observatory

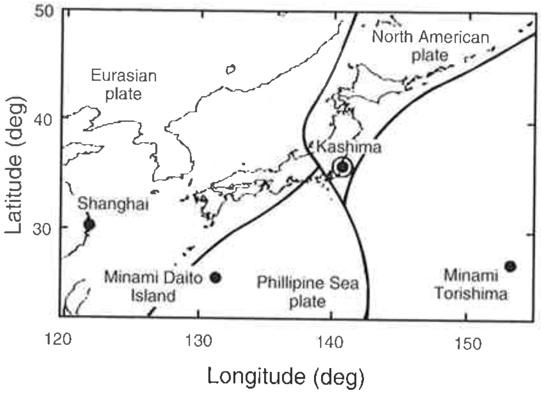


Fig. 1 Locations of the Western Pacific VLBI Network stations

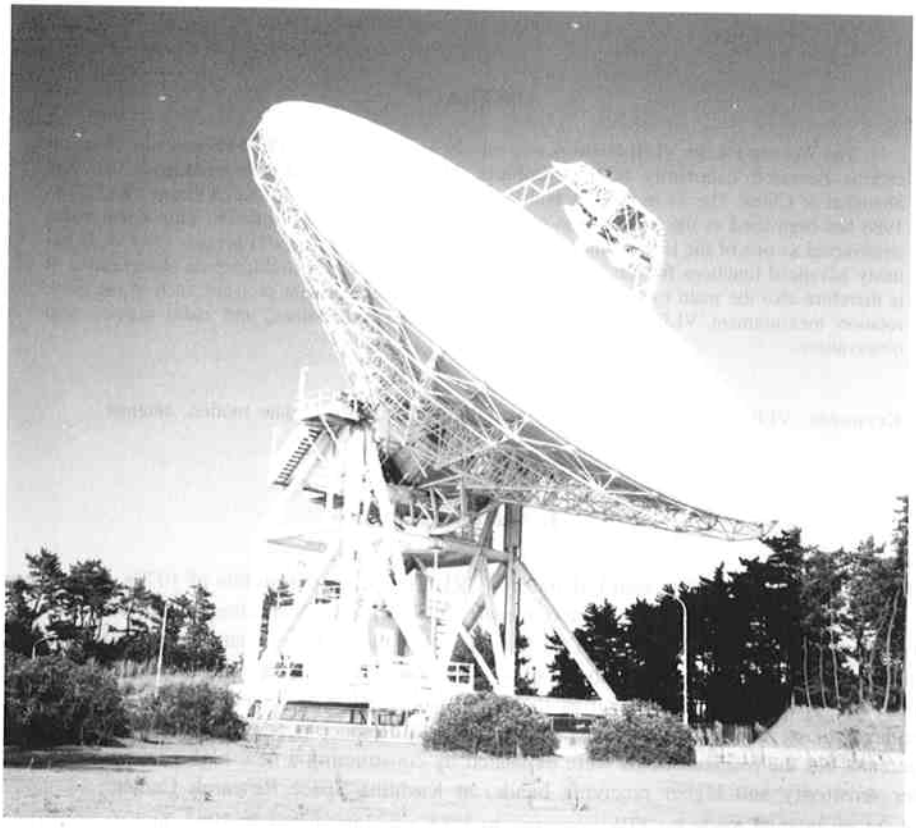


Fig. 2 Overview of the Kashima 34 m antenna

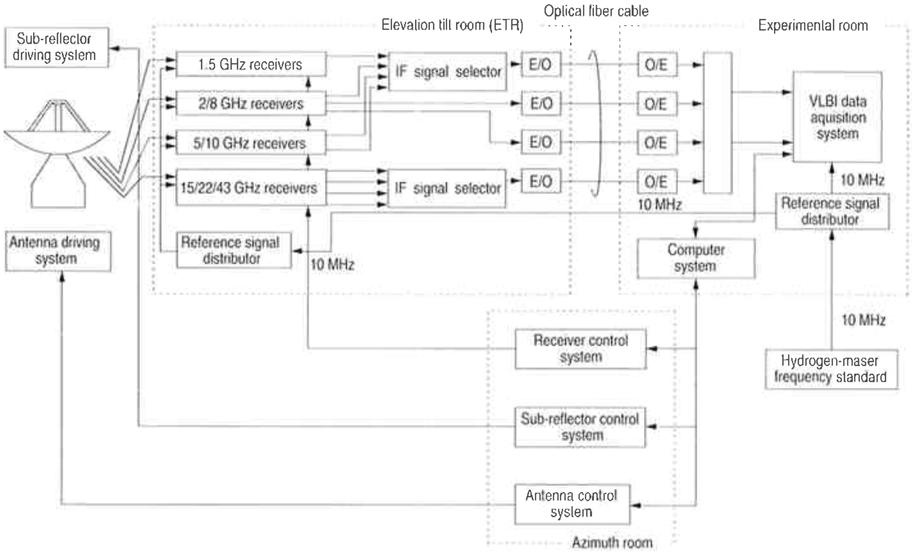


Fig. 3 Block diagram of the 34 m antenna system

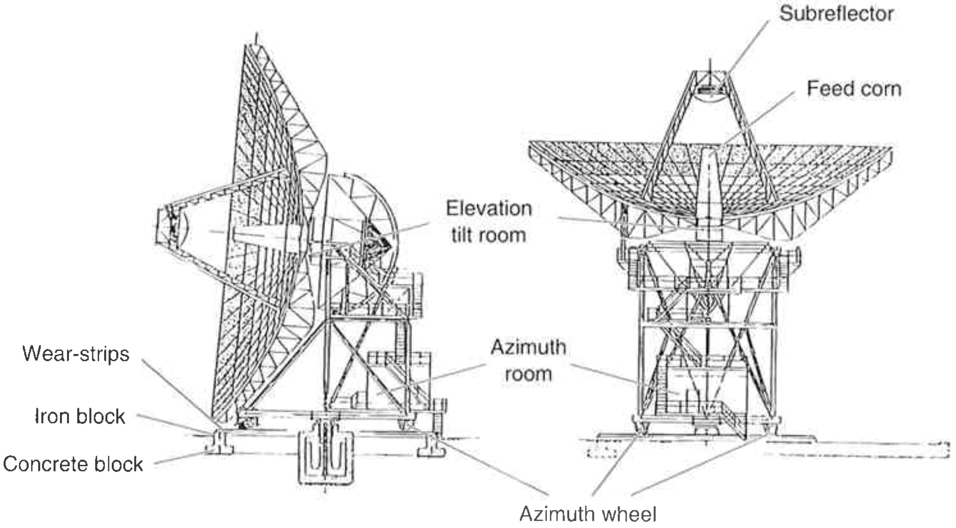


Fig. 4 Structure of the 34 m antenna

experiments," which was started in 1988 and is the main subject of this special issue. The main purpose of this project is to precisely measure the movements of the four main plates around the Japanese Islands in order to obtain the basic data for long-term earthquakes forecasts.

The main VLBI station of this project is the 34 m antenna at Kashima Space Research Center on the North American plate. At two stations on the Pacific plate and Philippine Sea plate, CRL placed a

Table 1 Mechanical specifications of 34 m antenna

Location	35°57′05.76″ N 140°39′36.16″ E
Antenna type	Cassegrain type
Mount type	Az-El mount
Aperture	34.073 m
Surface accuracy	0.17 mm (rms)
Diameter of the subreflector	3.8 m
Agreement of azimuth and elevation axis	<1 mm
Mounting style	Az-El mount
Driving speed	
Azimuth	0.7 degree/sec
Elevation	0.7 degree/sec
Drive range	
Azimuth	±359°
Elevation	6–90.7°
Subreflector moving range	
X-axis	±60 mm
Y-axis	±60 mm
Z-axis	±60 mm
Subreflector rotation range	
Around X-axis	±3.5°
Around Y-axis	±3.5°
Total weight	400 tons
Pointing resolution	1.235″

medium size VLBI station and a small transportable VLBI station(5). The fourth station, on the Eurasian plate, is the Shanghai station which belongs to the Shanghai Observatory of Chinese Academy of Science. Figure 1 shows the locations of the VLBI stations of this project. The Western Pacific VLBI Network experiments were performed from 1988 to 1993.

The 34 m antenna was designed as a multipurpose antenna, and is used for many purposes in addition to the Western Pacific VLBI Network experiments. This paper gives an overview of the 34 m antenna system.

2. Kashima 34 m Antenna

This antenna (Fig. 2) has a parabolic type main dish and it's aperture size is the third largest in Japan. (The largest antenna is the Institute of Space and Astronautical Science's 64 m antenna at Usuda, and the second largest is the National Astronomical Observatory's 45 m antenna at Nobeyama.)

The basic design of this antenna is similar to those at the JPL (Jet Propulsion Laboratory) deep space tracking stations in California, Spain, and Australia, but many aspects were designed specially

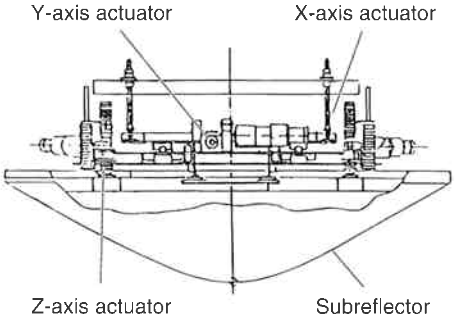


Fig. 5 Structure of the subreflector of the 34 m antenna

for the Kashima 34 m antenna. A simplified block diagram of the 34 m antenna system is shown in Fig. 3. The main features of this antenna are:

1) the high surface accuracy of main dish which can be used for millimeter wave observations,
2) multi-receivers system from 1.5 GHz band to 43 GHz band.

In this section we show the main performance and specifications of the 34 m antenna.

2.1 Mechanical Specifications

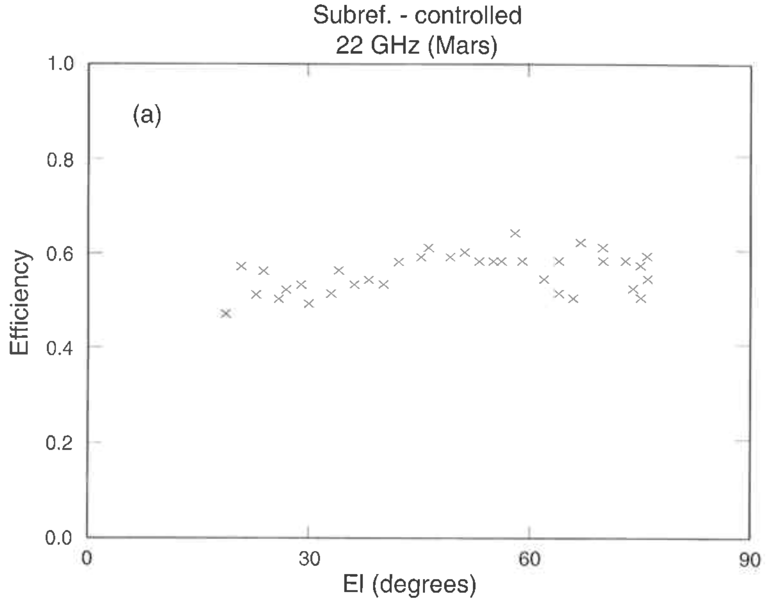
The Kashima 34 m antenna has an azimuth-elevation tracking system whose structure is illustrated in Fig. 4, and whose mechanical specifications are listed in Table 1. The tracking system used for the azimuth axis is the "rail tracking type," namely the main unit of the antenna system rotates on "the azimuth rail" to change the azimuth angle. Because one of the main study targets of this antenna is precise geodesy and the antenna is very heavy (about 400 tons), the basement of the azimuth rail is firmly connected to the hard ground by long piles, and consists of concrete blocks and iron blocks. The azimuth rail (called "wear-strips") has a thickness of about 3 cm and is made of hard steel fixed on the iron blocks by bolts. The wear-strips form a circle. If the surface of the wear-strips is damaged, it is only necessary to replace the wear-strips, and this can be easily performed. After the antenna was in operation for about 3 years, the surface of the wear-strips was damaged by rust and we exchanged them with new ones.

The main frame of the antenna is designed rigidly, and its driving system is also designed for the geodetic VLBI. That is, the geodetic purpose VLBI requires as many radio sources such as quasars as possible to be observed during 24 hours. The number of observations in a 24 hours experiment is more than 200. The azimuth and elevation driving speeds need therefore as fast as possible, and they are more than 0.7 degrees/sec, comparatively fast when compared with those of other large-aperture antennas.

This antenna also has the highly precise pointing accuracy, better than 7″, needed to perform the millimeter-wave observations. This positioning accuracy is performed by using the optical rotary encoders which have 20 bits of angular resolution.

2.2 Main Dish

The main dish of the 34 m antenna has a rigid structure and its surface was adjusted to be best at the elevation angle of 45 degrees, where its surface accuracy is about 0.17 mm (rms). Many factors



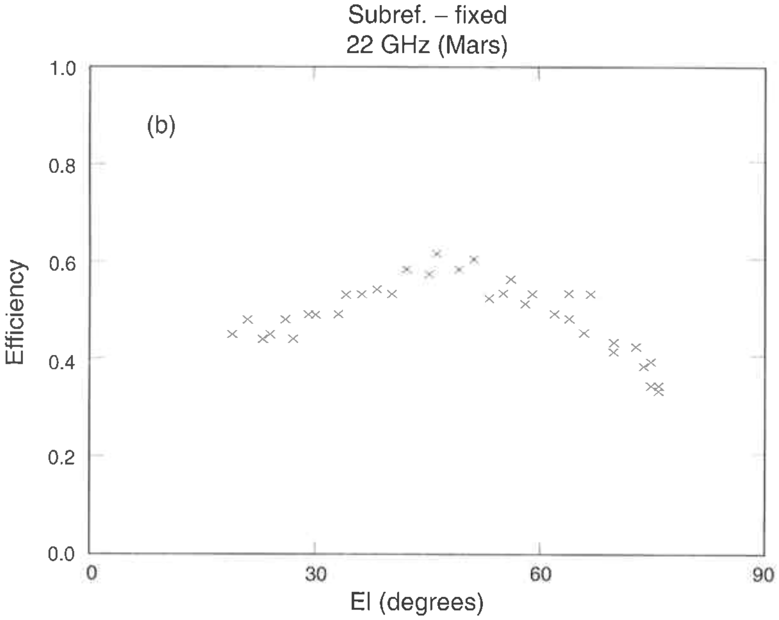


Fig. 6 Efficiency of the 34 m antenna at 22 GHz: (a) active subreflector control is on, (b) active subreflector control is off.

Table 2 Receivers specifications

Band	Frequency	Band width	T_{rec}	T_{sys}	Efficiency
1.5 GHz	1.35–1.75 GHz	400 MHz	10 K	38 K	68%
2 GHz	2.15–2.35 GHz	200 MHz	11 K	71 K	65%
5 GHz	4.60–5.10 GHz	500 MHz	25 K	60 K	71%
8 GHz[1]	8.18–8.60 GHz	420 MHz	8 K	48 K	56%
8 GHz[2]	8.18–8.60 GHz	420 MHz	12 K	53 K	56%
8 GHz[2]	7.86–8.36 GHz	500 MHz	13 K	56 K	58%
10 GHz	10.20–10.70 GHz	500 MHz	43 K	70 K	64%
15 GHz	14.40–14.90 GHz	600 MHz	42 K	106 K	51%
15 GHz	14.90–15.40 GHz	500 MHz	40 K	108 K	47%
22 GHz	21.88–22.38 GHz	500 MHz	101 K	189 K	58%
22 GHz	23.58–24.08 GHz	500 MHz	158 K	223 K	54%
43 GHz	42.80–43.30 GHz	500 MHz	400 K	1200 K	44%

T_{rec}: Receiver noise temperature
T_{sys}: System noise temperature at El = 90 degrees
1: 8 GHz receiver for normal receiving band
2: 8 GHz receiver for wide receiving band

such as gravitation, wind, and temperature, reduce the typical surface accuracy to about 0.3 mm (rms) during observations, but this value is still good enough for the millimeter-wave observations.

2.3 Subreflector

The beam optics of the antenna is a modified cassegrain type and its focal point is at "the feed corn" illustrated in Fig. 4. As it will described in a later section, it has a multireceiver system in the ETR (Elevation Tilt Room) to keep the focal point at the center of each receiver's feed horn (the subreflector is mechanically controlled to feed the received signal to the selected feed horn). Its structure is shown in Fig. 5. The subreflector can move along the X, Y, and Z axes and can rotate around the X and Y axes. This movement is accomplished by using five actuators, and their positioning accuracy is within 0.01 mm. The subreflector can be controlled to keep the maximum efficiency when the main dish shape is changed by the gravitational effect due to changes in elevation angle. This active subreflector control system is highly effective for observations at the higher frequencies, and Fig. 6(a) and 6(b) show results obtained with and without this control(6). When the active subreflector control is in operation, the efficiency can be kept almost constant for elevation angle changes from 20 degrees to 80 degrees, whereas efficiency is reduced at low and high elevation angles when active subreflector control is not in operation.

2.4 Receivers System

Table 2 lists the specifications of the receivers mounted in the 34 m antenna. In addition to receivers listed in Table 2, 300 MHz and 600 MHz receivers were mounted on the front feed point of the main dish when the antenna was constructed. The radio conditions at these bands were so bad around Kashima Space Research Center, that these receivers were removed.

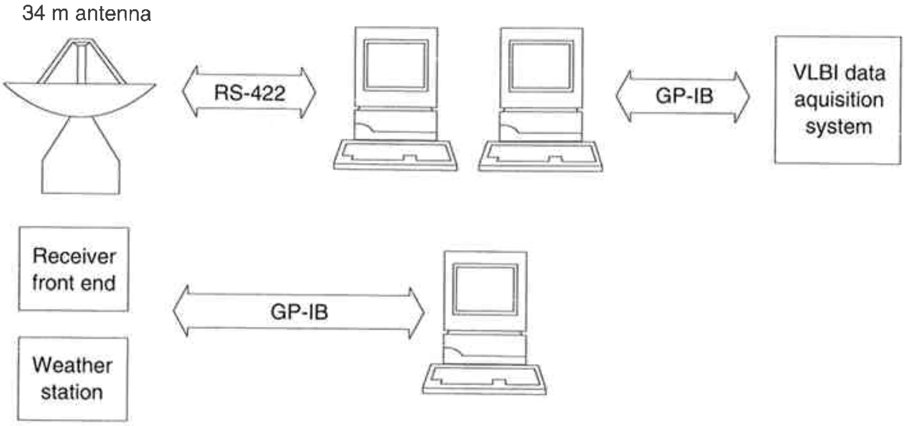


Fig. 7 Computer system for controlling the 34 m antenna

The receivers listed in Table 2 are cooled to 15 K by a closed-cycle gas helium system to reduce amplifier noise (each amplifier uses the High Electron Mobility Transistors). The receivers are separated into four groups;

Group 1; 1.5 GHz
Group 2; 2 GHz and 8 GHz
Group 3; 5 GHz and 10 GHz
Group 4; 15/22/43 GHz

Each group is mounted on a stage and when a receiver group is selected, it is moved by the trolley system to the focal point. The receiver groups can be exchanged from the experimental room by using the receiver control computer.

The receiver group 2, 2 GHz band and 8 GHz band, can receive signals simultaneously to perform the geodetic VLBI, and can provide ionospheric delay compensation. The other receivers cannot be used simultaneously, but the receivers can be exchanged within about 10 minutes.

Each receiver can select the receiving polarities, LHCP (Left Hand Circular Polarity) or RHCP (Right Hand Circular Polarization), of the receiving signal. This selection is also made from the experimental room by using a computer system.

2.5 Control System

The entire system of the 34 m antenna is controlled by small computers in the experimental room. In the VLBI experiments, three computer systems are used, one to control the antenna driving, the second one to control the receiver system, and the third one to control the VLBI equipment. Figure 7 shows the schematic diagram of the control system. The VLBI experiments are performed by using the operating software called "NKAOS," which was modified for the 34 m antenna from the KAOS (Kashima Automatically Observation System)(7) which was developed for the K-3 VLBI system.

3. Upgrading Efforts of the 34 m Antenna

3.1 Azimuth Wear-strip Cover

Because the Kashima Space Research Center is near the seaside, because the humidity and temperature in summer are high, and because of the operational form of the geodetic VLBI experiments, rust damaged the wear strips of the azimuth rail. After about three years operation the wear-strips were deeply rutted and made steps of about 1 mm at the joint points of the wear-strips. The wear-strips were therefore replaced in 1992, and to prevent further damage an azimuth rail cover was attached in 1993. The wear-strip is kept dry by the rail cover, which is expected to protect the wear-strip from rust and thereby ensure their long lifetime.

3.2 Optical-fiber IF Signal Transmission

When the 34 m antenna was constructed, coaxial cables were used as transmission lines for the intermediate frequency signal (IF signal) converted from the received band. These cables, too, were damaged by the humidity, especially at the junction points placed outside, and were therefore in 1992 replaced by high-performance optical-fiber cables. The resultant optical signal transmission system can transmit the wideband signal without amplitude equalizers whereas the coaxial cable needs, so it makes the transmission system for the IF signal very simple and is expected to improve the performance of the signal transmission.

3.3 New Millimeter-wave Receiving System

A 43 GHz receiver developed by Nobeyama Radio Observatory of NAO was mounted on the 34 m antenna by Nobeyama Radio Observatory in cooperation between CRL and NAO. It uses the HEMT-type low-noise amplifier but does not have a good noise temperature. The survey observation of SiO Masers and the 43 GHz VLBI experiments with the Nobeyama 45 m antenna were performed by using this 43 GHz receiver because the flux density of SiO masers are very high and the 34 m and 45 m antennas have very large apertures. But to perform more sensitive observations and for the VLBI experiment with smaller-aperture antennas, it is necessary to improve the receiver noise temperature. A new millimeter-wave receiver that uses the SIS (Superconductivity-Insulator-Superconductivity) mixer is therefore under development in a collaborative effort by CRL and NRO. This receiver is expected to greatly increase the sensitivity of the 40 GHz band receiving system of the 34 m antenna. A 100 GHz band SIS-type receiver system is also scheduled to be mounted on the 34 m antenna.

4. Observations Using the 34 m Antenna

The VLBI experiments using the Western Pacific VLBI Network system were performed from 1989 to 1993, and the details and results of these experiments are given in the papers in this special issue(8)-(11). This antenna has also been used, for many purpose, as a main tool of the precise space and time measurement project. The main subjects of this project are:

1) precise earth rotation measurement experiments,
2) developments of next-generation precise VLBI facilities and equipment(12),
3) radio astronomical observations(13),

4) investigation of interstellar propagation scintillation (IPS) due to solar wind,
5) precise timing signal observation of the high stable millisecond pulsar for the precise time scale(14).

There are also many proposals from many other organizations who want to use the 34 m antenna in collaborations with CRL.

5. Conclusion

The Western Pacific VLBI Network experiments were successfully performed using the 34 m antenna as a main VLBI station and the results and experience gained in those experiments applied for the new CRL project (called "Key Stone Project") which will precisely measure crustal deformation around the Tokyo Metropolitan area.

The Kashima 34 m antenna is the first large antenna that was imported to Japan. It is a very powerful observation tool, but we should make efforts that this antenna will be as our own tool and as a tool at the forefront of science.

6. Acknowledgment

We would like to express our thanks to everyone who helped to construct the Kashima 34 m antenna.

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