Vol. 38 No.3 *Journal of the Communications Research Laboratory* Printed in Tokyo, Japan November 1991 pp.393 – 397

RESULTS OF VLBI EXPERIMENTS AT THE COMMUNICATIONS RESEARCH LABORATORY (1984 – 1990)

I. INTRODUCTION

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The Communications Research Laboratory (CRL; formerly Radio Research Laboratories, RRL) has developed Very Long Baseline Interferometer (VLBI) systems such as the K-1, K-2, K-3, and K-4 types. CRL has also conducted domestic and international joint experiments with them, for fifteen years. The epoch began in 1980 when NASA and RRL agreed to start joint VLBI experiments, in 1984, for measurement of crustal plate motion. RRL succeeded as scheduled in developing the K-3 type VLBI system which needed to be compatible with the USA Mark-III system. This was only after overcoming some technical difficulties. Since the joint experiments started in 1984, RRL (or CRL) have carried out many joint experiments with international organizations in the USA, China, West Germany, Australia, Canada, Sweden and Italy as well as domestic experiments, for purposes such as plate motion measurement, geodetic survey, international time comparison and earth rotation observation.

This special issue will summarize the VLBI experimental results obtained at RRL and CRL from 1984 to 1990. Readers are recommended to refer to the references cited in each section for more detailed explanations. In this section the main results are summarized.

(1) The Initial Stage of VLBI System Developments at RRL

RRL started to develop a VLBI system independently in 1975. At that time, CRL was the only national organization having the necessary technology such as space communications, radio propagation and standard for frequency and time. RRL completed the first VLBI system, K-1 system, in 1976 using the USA's Mark-II system as a model. The first Japanese VLBI experiment was successfully completed with this system at the beginning of 1977 using the 26-m antenna of the RRL Kashima station and the 12.8-m antenna of NTT's Yokosuka Electrical Communication Laboratory(1). 1 MHz band width noise was received at 4 GHz from USA's ATS-1 satellite. The delay-time and phase were determined with errors of 1 ns and 6 degrees, respectively.

In the second stage, the K-2 system was developed for measurement of millimeter-wave scintillations in the ECS (Japanese Experimental Communications Satellite) millimeter-wave communications experiment. In the ECS project a microwave link was set up between the Kashima main-station and the Hiraiso sub-station for site-diversity experiments, and the observed data were transmitted in real-time from Hiraiso to Kashima for processing. The delay-time determination error was 0.1 ns using the frequency synthesis of 5 channels of the receiving frequency at 4 GHz. Each channel was 2 MHz wide, giving a total equivalent band width of 100 MHz(2). In both experiments, however, the baseline lengths could not be determined due to the limited integration time using a Cs frequency standard.

(2) Development of the K-3 System and Japan-USA Joint VLBI Experiments

RRL established a new 5-year plan in 1979 to develop the K-3 VLBI system. This was in response to a proposal, from Geodesy Council, to observe crustal movements and variations using space techniques such as VLBI and satellite laser ranging (SLR). Just after this a Japan-USA joint plan was agreed between NASA and the Japan Space Activities Commission, for studying crustal plate motion. On the basis of this, RRL and NASA agreed in 1980 to start a joint VLBI experiment in 1984(3). However, RRL radically changed the 5-year plan to develop K-3 system in order to make it compatible with the Mark-III system in USA.

The K-3 system was almost completed by October 1983, after various technical difficulties were overcome due to full cooperation from the USA(4). It is a comprehensive system for receiving the signals to be processed and recorded and for analyzing data to determine various parameters such as baseline lengths(5). Through this system development, RRL accumulated a lot of experience and expertise which enabled it to later develop an improved version; the K-4 system. This was much smaller, lighter and had a higher performance.

In November 1983 the first Japan-USA joint VLBI experiment was conducted in order to test the K-3 system performance, including compatibility with the Mark-III. The Kashima 26-m station, the Majave VLBI station (12-m) and the Owensvalley Radio observation station (40-m) joined in. The experiment was successful and achieved a delay-time determination error of 0.1 ns with the frequency synthesis of 8 channels at 8 GHz and 6 channels at 2 GHz, each of which was 2 MHz wide giving a total width of 400 MHz(6). In January to February 1984, Japan-USA system level experiments were made between Kashima, Mojave and Hatcreek with full time observation of 24 hours to attain a successful determination of the baseline lengths between the continents with error of about 3 cm(7).

Japan-USA joint experiments followed it with baselines of more than 6,000 km such as those between Fairbanks, Mojave, Hatcreek, Vandenberg, Haystack, Kauai, Kuwajalein, Onsala (Sweden), Wettzell (Germany) and Kashima. They resulted in reporoducibility in the order of 10^{-9} during 6-year experiments. They detected plate motions which turned out to agree well with plate motion models such as RM-2(8). Plate motions up to that time had only been estimated by observing various phenomena carved on the earth over a very long historical period. The VLBI experiments have made clear that those earlier estimates were basically right. VLBI has also shown that it is possible to measure movements occuring over comparatively very short intervals because of the high precision of VLBI.

(3) Japan-USA Time Comparison Experiments

From the end of 1984 RRL and US Naval Observatory (USNO) made regular VLBI experiments for 5 years to compare UTC (RRL) and UTC (USNO) which were the standard times in both countries. The precision was about 0.1 ns and the accuracy was about 1 ns(9). Those results compare well with a precision of 10 ns and accuracy of tens of nanoseconds by the Global Positioning System (GPS) which is the present main system for the international time comparison network. The accuracy was determined by a zero-baseline experiment using a small receiver from RRL which was carried to USNO to measure the instrumental delay difference between the two VLBI stations(10). The problem yet to be solved is the creation of a high precision and accurate link between the VLBI station and the organization where the standard time is generated.

(4) Domestic VLBI Experiments for Geodetic Survey

The Geographical Survey Institute (GSI) in Japan constructed a transportable 5-m antenna station with the K-3 system under the cooperation of RRL in 1984. This was for readjustment of the domestic geodetic survey network. Experiments started in 1984 between the Kashima 26-m station and the Tukuba 5-m station. The 5 m station was transported to Miyazaki Prefecture in 1986 and 1988, Chichijima island in 1987 and 1989 and to Hokkaido in 1990.
Reproducibility of the experiments was about 1 cm(11). Chichijima island is on the Philippine Sea Plate, and the movement of this plate was detected for the first time(12). CRL made its own VLBI experiments using a very small transportable system consisting of a 3-m antenna station used in conjunction with the K-4 system(13).

It was taken to Okinawa and Wakkanai in Hokkaido to establish reference points for the geodetic survey for use in satellite ranging.

(5) Japan-China Joint VLBI Experiments

Based on the Japan-China science and technology agreement, the VLBI experiments started in 1985 between the Kashima station and the 6-m station at Shanghai Observatory which is on the Eurasian plate. The VLBI back-end system and others to be installed in the Chinese station were shipped from RRL accompanied by operating staff. In this experiment a high
density Cassette-recordes (factor of 7 higher density than the one previously used) was successfully used(14). After that China constructed a 25-m antenna station at Seshan with a Mark-III back-end system and China has also joined in the Japan-USA and CRL domestic experiments(15). Exchanges of staff between both institutes have been made regularly.

(6) Observations of the Earth Rotation

VLBI makes observation of the earth's rotation possible with a precision of two orders higher than achieved with optical observation, for example experiments to measure the polar motion and the variation of the rotation rate. RRL (CRL) joined with NASA for the polar area experiments and with IRIS-P for the earth rotation observation. Meanwhile a Japan-Germany (Kashima with Bonn University) joint experiment was successfully conducted in 1985 with a baseline length of more than 8,500 km(16), and since 1988 Japan-Australia (CSIRO) experiments have been carried out for the same purpose using telescopes at Kashima and Tidbinbilla(17). Recently, the International Earth Rotation Service (IERS) has formally decided to adopt space geodetic techniques for earth rotation observation and is trying to establish an international observation network. CRL intends to cooperate fully with IERS(18).

(7) Construction of a Domestic West-Pacific Experiment Network

There are Japanese islands on the Pacific plate, the Eurasian plate, the Philippine Sea plate and the North American plate. Some earthquakes have occured these inlands. It is therefore important to construct our own VLBI network with a station on each plate. CRL succeeded in getting a special fund from our government to construct such a network with a 34 m-antenna station at Kashima (supposedly on the North American plate), two 10 m-antennas stations at Minami Daitojima (on the Philippine Sea plate) and Minami Torishima (on the Pacific plate)(19). An experiment started in 1989 together with the 3 m-antenna station and K-4 system with a 5 year plan. The baseline length between Kashima and Minami Torishima turned out to be decreasing by 4 cm a year(20).

(8) The First Antarctica VLBI Experiment

The National Institute of Polar Research decided to construct an ll-m antenna station to receive signals from the EXOS-D satellite. It is located at the Showa Station in Antarctica and will be used as a VLBI station in the future by cooperation with CRL. In order to carry out preliminary experiments, staff from CRL joined the 30th Antarctic regional observation party. They cooperated in constructing the antenna and setting up VLBI receiving equipment. A K-4 system was brought to Antarctica by the 31st party. A VLBI experiment was then successfully conducted twice in January 1990. Kashima station and the Tidbinbilla station in Australia joined these experiments to obtain the baseline length of 11,391,620.78-m with an error of 17 cm[21]. They were the first experiments in the world made with a VLBI station on the Antarctic plate. In the near future regular observations will be made with a permanent VLBI system.

(9) The Future Plan

The Japan-USA joint experiment which was the first five-year plan ended in 1988. It was followed by the second joint experiment plan which will finish in 1991. A new plan called DOSE (Dynamics of Solid Earth) will follow it and CRL has agreed to join it in response to a request from NASA.

The experience gained by VLBI system development at CRL made it possible to develop the K-4 system, the back-end of which is a fifth the size and one third the weight of the K-3 system. The high density recorder.is a Cassette type weighing only 55 kg. CRL has been nominated by IERS as one of the VLBI technology development centers together with Haystack Observatory in the USA.

VLBL experiments at CRL have been increased in scope from geodetic applications in the early stages to international time comparison; earth rotation observation; astronomical radio-wave observation in microwave, 22 GHz and millimeter wave bands; wave-front clock VLBI observation with Canada; timing observation of millisecond pulsars, and others. Partners for international joint experiments have also increased to include the USA, China, West Germany, Australia, Canada, Sweden, Italy and the Soviet Union. In the future, the earth rotation observation will be a priority for CRL as it is the organization in charge of national standard time. CRL intends to establish the future "space standard time". CRL will most certainly contribute to the development of science and technology through VLBI.

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