

## EARTH ROTATION MONITORING WITH K-3 TYPE VERY LONG BASELINE INTERFEROMETRY SYSTEM

### —Study of Possible Systematic Errors Appearing in the Earth Rotation Monitoring with Single and Multi Baseline VLBI—

By  
Taizoh YOSHINO

#### ABSTRACT

A Very Long Baseline Interferometry (VLBI) software system, which utilizes a data base accessible from an entire software system, was developed at the Communications Research Laboratory (CRL) for global geodesy and the Earth rotation monitoring. Using this system, we carried out the Earth rotation VLBI experiment with S and X frequency bands. The experiments comprised a single-baseline VLBI experiment (German-Japanese Earth Rotation Observations; GJRO campaign) and a multi-baseline VLBI experiment (International Radio Interferometric Surveying; IRIS-Pacific VLBI network). Through the experiments, we found systematic offsets between the Earth Rotation Parameter (ERP) determined by our measurements and ERP from other VLBI networks with both single-baseline and multi-baseline configurations. In the single-baseline experiment (GJRO campaign), UT1 is determined with 0.1 msec precision, and systematic offsets with other UT1 results are removed by adopting the published IRIS pole positions as *a priori* values. Thereby the accuracy of the UT1 determination with the single-baseline VLBI was within 0.2 msec. In the multi-baseline experiment (IRIS-P), obtained ERP becomes as accurate as other regular VLBI results by unifying all IRIS-P station positions with the IRIS coordinate system. The determined ERP by IRIS-P coincides with ones by other networks within 1 milli arc second on average. According to UT1 data analysis in the GJRO campaign, it is concluded that the theoretical amplitude of the 13.66 day tidal term increases by 5 to 10%. It is shown that an accurate ERP determination with an independent VLBI network becomes possible only by a consistent set of reference frames. Precise time comparison data between Kashima (CRL/Japan) and Richmond (USNO/USA) with 1 nsec accuracy is also obtained through an IRIS-P experiment as another observable. The influence of atmospheric excess path delay and the foundation of the VLBI antenna for global geodesy and the Earth rotation monitoring, are also discussed.

#### 1. Introduction

Until a decade ago astrometry was based mainly on optical observations, in which the accuracy was limited by the angular uncertainty determined by atmospheric scintillation. Recently Very Long Baseline Interferometry (VLBI) using radio telescopes with baseline length of thousands of kilometers has overcome the problem. The available angular precision by VLBI is

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now better than 1 milli arc seconds, which is one hundred times better than that of optical telescopes. VLBI is one of the modern space techniques to determine UT1, pole position, precision and nutation (the Earth Rotation Parameters: ERP) more precisely than the conventional optical method. VLBI is now one of the best tools to make more precise astrometry and Earth rotation monitoring and making revolution in astrometry. It provides us not only with a lot of new knowledge with respect to radio astrometry and Earth physics, but is also a tool for the navigation of space vehicles in deep space.

This thesis mainly addresses the following two topics: 1) VLBI software system development for global geodesy and the Earth rotation monitoring and 2) precise Earth rotation monitoring in a consistent reference frame.

A VLBI system in each station consists of a large aperture radio telescope, low noise receiver, data acquisition terminal including data recorder for mass data storage, stable atomic clock and automatic controlling system. At least one data processor is required for data reduction. In addition, large software system for scheduling, data processing, data analysis and data management is required. To start global VLBI observations for geodesy and earth rotation monitoring, all of these hardware and software systems were developed at Kashima by measuring compatibility with the Mark III system developed by NASA in the United States. The developed system was named K-3. The structure of the K-3 software system is designed using the IMAGE-1000 commercial data base system, which is accessible from all K-3 software systems except for the automatic operation system. Since the structure of data base affects utilization of whole K-3 software system, the design was made carefully. Thereby each VLBI data is available efficiently from the K-3 data base. This ensures consistent data even in a large software system.

The IRIS (International Radio Interferometric Surveying) program for monitoring the Earth rotation by VLBI succeeds as one of the International Earth Rotation Service (IERS) programs started in January, 1988. The VLBI networks called IRIS-P (Pacific) and IRIS-S (Southern hemisphere)<sup>(1)</sup> began observations independently of the US-Europe IRIS-Atlantic (IRIS-A) network in the IERS program. The IRIS-P network is made to study independent and precise ERP monitoring with four stations for future IERS activity. Independent VLBI networks are required not only for the support of other networks, but also for increasing the reliability of ERP results. In particular, independent VLBI experiments require a unique reference frame which is necessary to have international service. A VLBI experiment is carried out every month by the IRIS-P network, every winter by the IRIS-S network, and in particular, every five days by the Atlantic network for regular ERP publication. Moreover, VLBI is useful for global geodesy. Hence, the CDP (Crustal Dynamics Project) program has also been carried out by NASA, in association with other international research teams, including Kashima, to study plate motion and crustal deformation<sup>(2)</sup>. Other regional campaigns for geodesy, are also carried out<sup>(3)</sup>.

To exploit the VLBI in UT1 monitoring, a campaign called GJRO (German-Japanese Earth Rotation Observations) was carried out in 1985 with a single baseline between Japan and Germany. Observing frequencies were S and X bands. In GJRO a systematic offset in UT1 was found when it was compared with the published UT1 series by IRIS-A. Also in IRIS-P, a systematic offset was found on each ERP compared with the published ERP by IRIS-A. By monitoring the Earth rotation independently, with other VLBI networks, it is possible to get reliable ERP results. Although ERP offsets among networks are often removed to study the variation of them only by practical reasons without deep understanding, they must be often a good indication of an inconsistent analysis of reference frame. In this paper, we studied how the systematic offsets appears in both single- and multi-baseline VLBI networks. The major source for

an offset is often the inconsistency of adopted reference frames in the analysis. After removing the UT1 offsets from GJRO data, fortnightly period UT1 variation due to a tide is also examined in a consistent data set and reference frame.

The purpose of the IERS is not only to monitor the Earth rotation, but also to establish and maintain the celestial and terrestrial reference frames. The construction of CIS (Conventional Inertial System) as a reliable celestial coordinate system shows a reference for CTS (Conventional Terrestrial reference System) through ERP monitoring by VLBI in IERS programs, where the two coordinate systems are connected to other. And the UT1 time scale is connected to the time system maintained by atomic clocks. Through upgrading the reference frame and extending the network on a global scale, it is expected to bring new knowledge in radio astrometry as well as geodesy.

In section 2, I describe fundamentals of Earth rotation observation by VLBI. In section 3, K-3 VLBI software system developed for global geodesy and the Earth rotation monitoring is described focusing on the data base system. I studied the Earth rotation determination and the reference frame in section 4 using a series of single baseline observation and multi baselines observations by VLBI. Time synchronization error is described there as a by-product of VLBI in a consistent reference frame. And geophysical condition of VLBI station is also described for a reliable monitoring in geodesy and Earth rotation. In appendices, fundamentals of tidal potential, expressions of rotational matrices and details of K-3 data base are described.

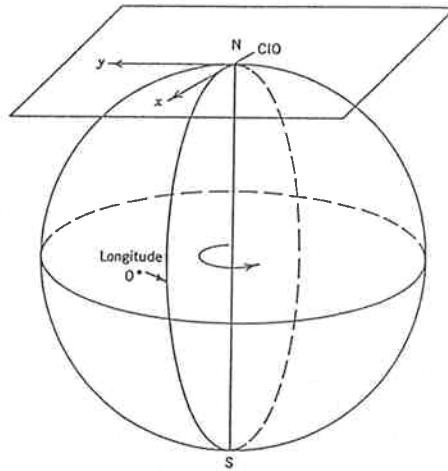
## 2. Fundamentals of Earth Rotation Observation by VLBI

In addition to precession and nutation, the movement of the geographic poles over the surface of the Earth called polar motion, and Universal Time (UT1) are fundamental in astrometry because they change the apparent direction of the sources from the observer on the Earth. The pole positions are expressed with respect to CIO (Conventional International Origin) as in Fig. 1<sup>(4)</sup>. Spin of the Earth is expressed either with the time difference between UT1 and the Coordinated Universal Time as (UT1-UTC) or with length of day. Since polar motion is influenced by the change of atmospheric angular momentum and the physical characteristics of the Earth's inner structure, in particular by the liquid core of which little is known, precise prediction of the pole position is still difficult. Conversely, the inner structure of the Earth may be understood through polar motion.

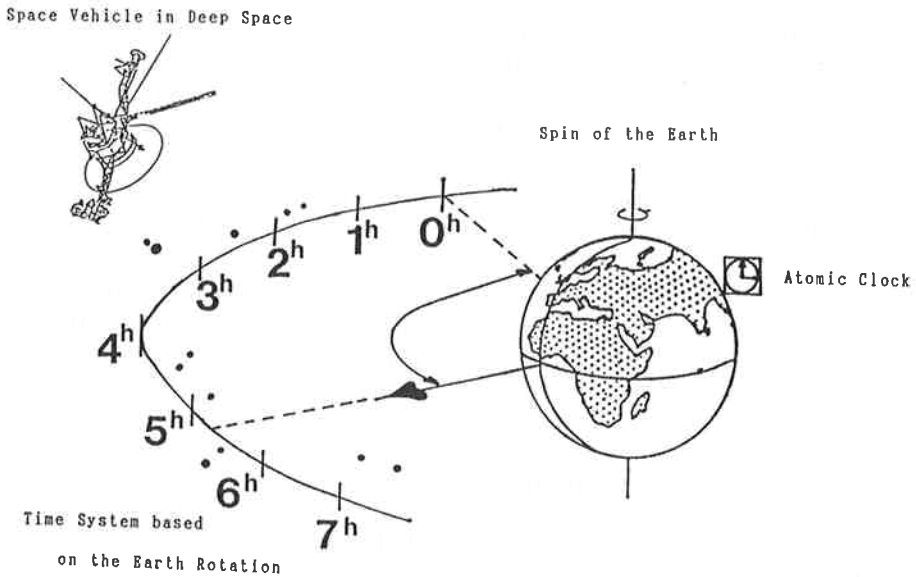
Earth rotation monitoring is also useful to connect the celestial reference frame with the terrestrial reference frame. Moreover, connection of UT1 and UTC is also required. Hence ERP are fundamental to pinpoint celestial objects precisely. Thus, ERP are used for precise tracking of satellites for gravitational field studies, laser ranging for studying lunar motion and precise maneuvering in deep space<sup>(5)</sup> (Fig. 2). Reliable ERP is available not only with the development of observing system, but also with stations which has a stable foundation in land and whose positions are regularly monitored relatively with other stations.

### 2.1 Fluctuations of the Spin of the Earth and Pole Wandering

The Earth seemingly rotates smoothly. However, the spin rate is always changing irregularly due to the deformation of the Earth, winds, ocean currents, and the inner structure of the Earth (Fig. 3), as well as the external tidal forces of the Sun and Moon. The relationship between the main forces affecting the Earth rotation is shown in Fig. 4<sup>(6)</sup>. Additionally the instantaneous pole



**Fig. 1** Coordinate system for the measurement of polar motion. The x axis is in the Greenwich meridian and the y axis is 90 degrees to the west. CIO is the Conventional International Origin<sup>(4)</sup>.



**Fig. 2** Earth rotation and maneuvering of space vehicles in Deep Space.

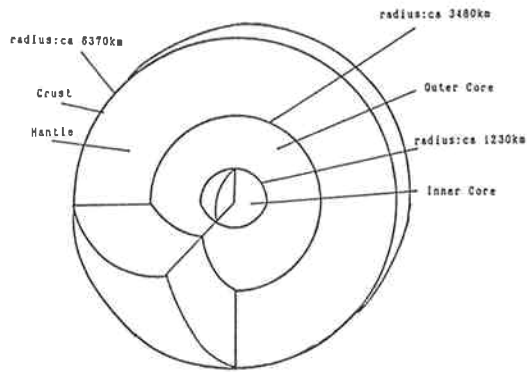


Fig. 3 Inner structure of the Earth.

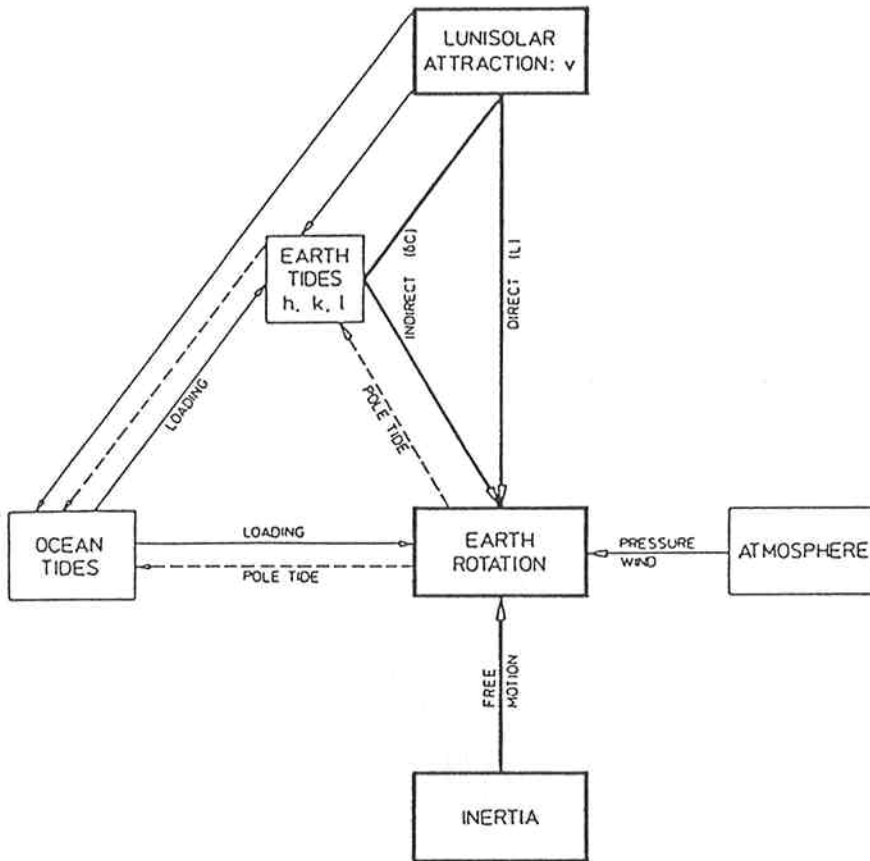


Fig. 4 Main forces affecting Earth rotation<sup>(8)</sup>.

of rotation is also moving irregularly with respect to the solid Earth. This is called polar motion. An example of polar motion and UT1 are shown in Fig. 5(a) and (b).

A dominant effect in the Earth rotation fluctuation is a secular change in Length of Day (l.o.d.). It is mainly caused by tidal friction in the oceans. L.o.d. is often used to show fluctuation of the spin of the Earth as well as UT1. A change in UT1 and a change in l.o.d. are related by

$$\begin{aligned} d(\text{UT1}) &= \int \frac{\delta\omega}{\Omega} dt \\ &= -\int \frac{\delta\Delta}{\Lambda_0} dt, \dots\dots\dots (1) \end{aligned}$$

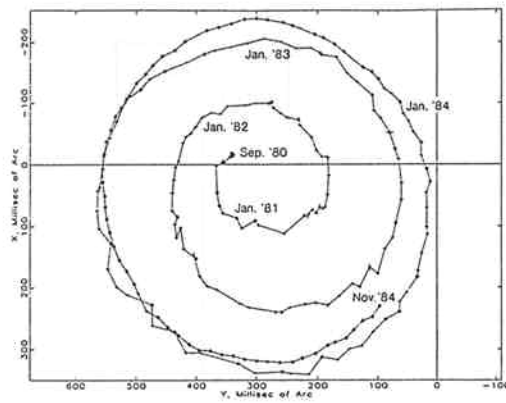


Fig. 5 (a) Locus of polar motion<sup>(58)</sup>.

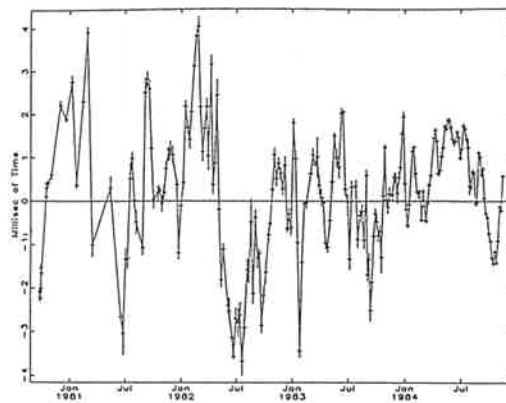


Fig. 5 (b) Determined UT1 shown as differences from the corresponding BIH CD values<sup>(58)</sup>.

where  $\omega$  is instantaneous angular velocity of the Earth, and  $\Omega$  is a mean value of angular velocity of the Earth ( $2\pi/86400$ ). And l.o.d. ( $A$  and  $A_0$ ) are expressed as

$$A = \frac{2\pi}{\omega} \dots\dots\dots (2)$$

and

$$A_0 = \frac{2\pi}{\Omega} \dots\dots\dots (3)$$

The variation of the observed Earth rotation is seen in a frequency domain in Fig. 6 (a) and (b). Angular momentum  $L$  is a product of moment of inertia  $C$  about the spin axis and angular velocity  $\omega$ : Eq. (4). According to the law of angular momentum conservation,  $L$  is constant if we do not take account of the slow and small change of  $L$  due to the tidal force. Thus the relation between small variation in  $\omega$  and  $C$  is expressed in Eq. (5).

$$C\omega = L \dots\dots\dots (4)$$

$$\frac{\Delta\omega}{\omega} = -\frac{\Delta C}{C} \dots\dots\dots (5)$$

Earth tides are also major factors inducing periodic Earth rotation fluctuations, because they change the moment of inertia about the Earth spin axis. Since Earth tides are induced by the luni-solar attraction, there are many frequency components corresponding to the motion of the Sun and Moon. The period and amplitude of each tide are complied by the calculation based on theoretical Earth model and the observation by modern techniques. They were listed by Yoder<sup>(7)</sup>. And in particular, short term tides are studied by Schuh<sup>(8)</sup> using VLBI data.

If the mass  $M$  is located at a distance  $r$  from the mass center of the Earth (Fig.7), tidal gravitational potential  $U$  is expressed as<sup>(9)</sup> (See Appendix 1),

$$U = \frac{3}{4} GM \frac{a^2}{r^3} \{ \cos^2\phi \cos^2\delta \cos 2H + \sin 2\phi \sin 2\delta \cos H + 3(\sin^2\phi - 1/3)(\sin^2\delta - 1/3) \}, \dots\dots\dots (6)$$

where  $G$  is the gravitational constant,  $a$  is the Earth radius,  $\phi$  is the latitude in a geocentric coordinate,  $\delta$  is the declination of a perturbing body  $M$  and  $H$  is the local hour angle. The three terms in Eq.(6) represent functions of spherical harmonics. The first term is sectorial function (Fig.8(a)). The second term is tesseral function (Fig.8(b)). The third term is zonal function (Fig.8(c)). Since only zonal tide about the spin axis has symmetrical influence as a function of the latitude, it changes the moment of inertia of the Earth. Hence zonal Earth tide causes UT1 variation. The fundamental period of zonal tide is fourteen days in the case of the Moon and six months in the case of the Sun because of the squared sinusoidal function of the declination.

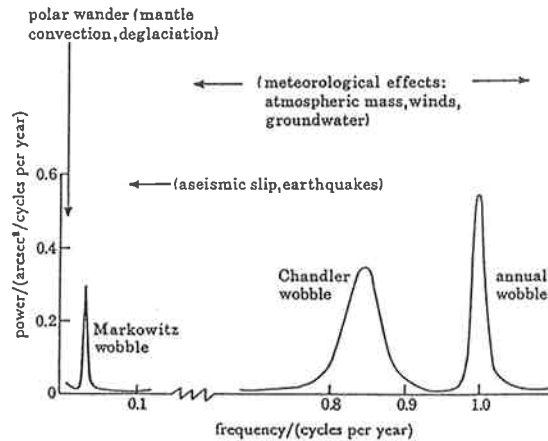


Fig. 6 (a) Schematic spectrum of the Earth's polar motion and possible excitation mechanisms<sup>(59)</sup>.

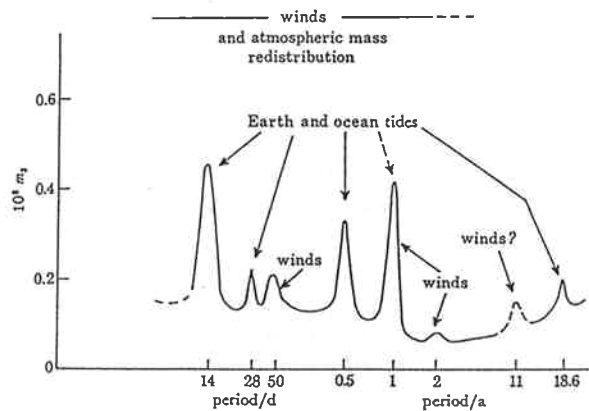


Fig. 6 (b) Schematic spectrum of the Earth's changes in length of day and possible excitation mechanisms<sup>(59)</sup>.

The periods of dominant tides longer than five days are six months, 27 days and 14 days. These tides are named SSa, Mm and Mf. Each of them is the abbreviation of Sun Semi-annual, Moon monthly, and Moon fortnightly. The UT1 variations due to the latter two tides are important factors to determine the Love number precisely. The two short-period variations (Mm and Mf) are caused by zonal tides on the rotation of the Earth. Through the precise VLBI observation of Mm and Mf tidal term, the frequency dependence of  $Q$  (Quality factor) is also obtainable. The SSa tide is related to semi-annual atmospheric excitation, and other theoretically-known small oscillations are below the observational errors.



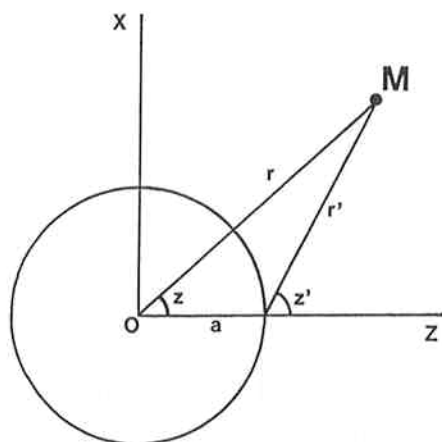
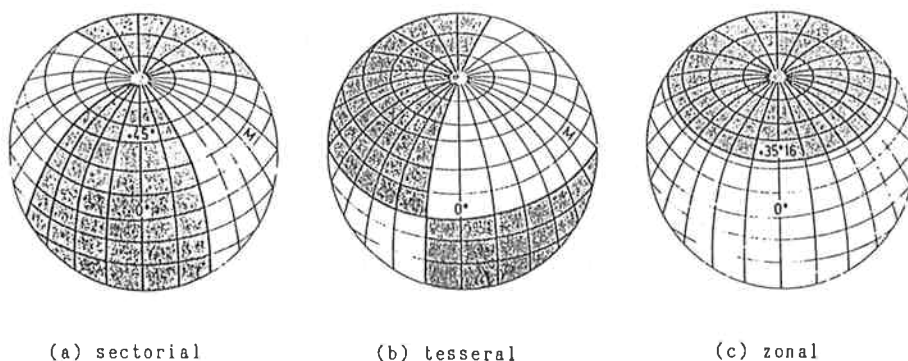


Fig. 7 Geometry of tidal analysis.



(a) sectorial

(b) tesseral

(c) zonal

Fig. 8 The three kinds of tides<sup>(9)</sup>.

Atmospheric angular momentum changes also induce fluctuations of the Earth rotation velocity, because the atmospheric angular momentum is coupled to the angular momentum of the Earth<sup>(10)</sup>.

Pole position wandering has two major frequency components, which are of 12 and 14 month periods. The former period is induced by the annual redistribution of the angular momentum of water and atmosphere on the Earth. The latter, which is called the Chandler wobble, is a free oscillation. Their behaviors are determined not only by the density and elasticity of the Earth but also through the characteristics of the ocean and atmosphere. However, the driving force of the Chandler wobble is still a question.

## 2.2 Earth Rotation Measurements by VLBI

The principles of VLBI and its application to the Earth rotation measurement are outlined here. In the beginning, the geometry of VLBI is shown in Fig.9. A radio signal transmitted from an extragalactic source, such as a quasar, is received with the same time schedule at more than two

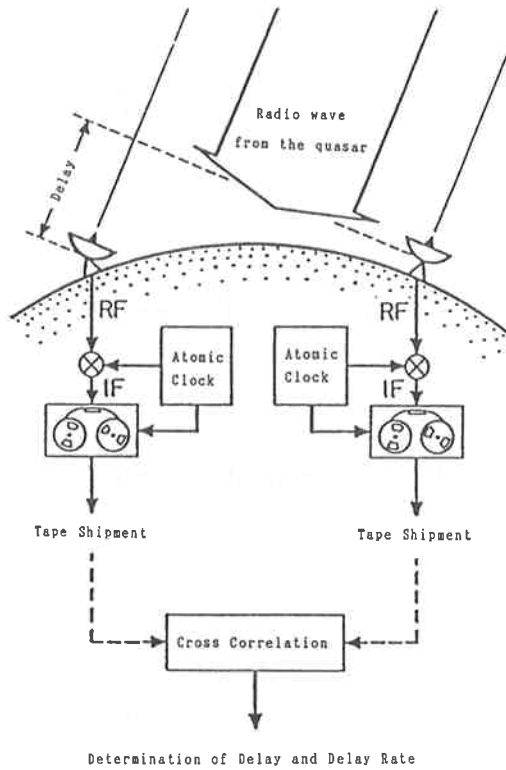


Fig. 9 Concept of VLBI.

stations, normally using large aperture antennas. Radio frequency (RF) signals are converted to video band signals. Then the signal is one-bit sampled with the Nyquist frequency, and recorded onto magnetic tapes at a high recording speed. The recorded tapes are transported to a data processing station for cross correlation. Then a data base is produced with the processed data, logged data, and calculated delay / delay rate and its partial derivative from physical models. Finally, ERP are obtained by analyzing these data.

The entire K-3 VLBI hardware system is described by Kawaguchi et al.<sup>(11)</sup> The remarkable progress in the VLBI technique, compared to that of a conventional radio interferometer, is primarily due to the development of an extremely stable local oscillator (Hydrogen maser) and tape recording system of massive data. The concept of the K-3 system is the same as that of the Mark III system, so that the functions may be compatible with each other. A specific feature of the K-3 system is a unified hardware control using an IEEE-488 bus. Since no other device control software is adopted in the K-3 system, the automatic control software for the VLBI system is relatively easier than that of the Mark III.

An interferometric delay time  $\tau$  provides information about a baseline vector ( $B$ ), a source vector ( $s$ ) and Earth rotation as<sup>(12)</sup>

$$\tau = [ P ] [ N ] [ S ] [ W ] B \cdot s / c, \dots \dots \dots (7)$$

where P is the precession, N is the nutation, S is the spin of the Earth and W is the wobble (polar motion). P, N, S and W are expressed in rotational matrix forms (Appendix 2) as:

$$[P] = R_z(z)R_y(-\theta_0)R_z(\zeta_0), \dots\dots\dots (8)$$

$$[N] = \begin{bmatrix} 1 & -\delta\psi \cos \epsilon & -\delta\psi \sin \epsilon \\ \delta\psi \cos \epsilon & 1 & -\delta\epsilon \\ \delta\psi \sin \epsilon & \delta\epsilon & 1 \end{bmatrix}, \dots\dots\dots (9)$$

$$[S] = \begin{bmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix}, \dots\dots\dots (10)$$

and

$$[W] = \begin{bmatrix} 1 & 0 & -W_x \\ 0 & 1 & W_y \\ W_x & -W_y & 1 \end{bmatrix}, \dots\dots\dots (11)$$

where  $\delta\epsilon$  is a nutation in obliquity,  $\delta\psi$  is a nutation in longitude,  $\theta$  is GAST (Greenwich Apparent Sidereal Time),  $W_x$  is x-pole position and  $W_y$  is y-pole position. Here the notations of  $z$ ,  $\zeta_0$  and  $\theta_0$  follow Lieske<sup>(13)</sup>. Using the physical models of precession, nutation, spin of the Earth and wobble, partial derivatives and *a priori* values to the delay and delay rate are calculated. Then ERP are finally determined from the difference between observed and calculated values using the least squares method.

According to Eq.(7), a baseline vector change has an influence on ERP estimation. Actually, plate motion and crustal deformation cause the baseline vector change. Hence, the change of the baseline vector should also be monitored by multi-baseline VLBI to identify the deformations. Using an iterative method or a global solution for a series of experiments, it is possible to estimate both ERP and station coordinates.

### 2.3 VLBI Reference Coordinate System

A reliable reference system is fundamental for astrometry and geodesy. The reference frame should be defined in an inertial system. According to Mach's principle, an inertial frame is fixed with respect to the rest of the material in the universe, and the origin of the coordinate is not accelerated with respect to the rest of the universe<sup>(14)</sup>. Since a radio reference coordinate system using extragalactic sources is regarded as a good approximation of an inertial reference frame, each position of extragalactic radio sources in the celestial sphere can be used as the reference points in an extremely stable coordinate system for astrometric observations. Thus extragalactic

radio sources are used in VLBI observations for astrometry and geodesy instead of galactic objects. Thereby influences of solar motion and galactic rotation are avoidable.

Geodetic measurements by VLBI should be made in an inertial reference frame observing celestial radio sources, while observations are made from the surface of deformable Earth. Hence, it is necessary to establish an Earth fixed reference frame using VLBI stations as reference points which is an averaged position in the terrestrial frame with deformation due to periodic tidal changes and other effects. For precise calculation of VLBI observables, a barycentric origin is used as the original point of the terrestrial coordinate, rather than a heliocentric origin.

In a geodetic VLBI, delay and delay rates are determined by the geometrical configurations of the baseline vector between stations on the Earth and the source vector to extragalactic radio sources. Since any errors in the celestial radio reference frame lead to errors in the terrestrial reference frame and vice versa, it is important to be careful about the adopted reference frames when VLBI networks extend to the other stations whose positions are determined by independent programs.

To define right ascension and declination in a celestial sphere, a real reference source or a source position catalog is needed. A strong quasar such as 3C273B has been regarded in the past as a reference source in a celestial sphere<sup>(15)</sup>. Since it is not a point source, but has a structure, the radio source, 0229 $\frac{7}{8}$ 131, is proposed as a new reference point instead of 3C273B<sup>(16)</sup>. As another approach, Ma defined the right ascension zero point in his catalog by minimizing the difference of the right ascensions of the 28 extragalactic sources between radio and FK5 optical source positions<sup>(17)</sup>. To define the terrestrial coordinate, the geodetic position of Haystack Observatory (US) was determined using VLBI and other space techniques so that the original point of the VLBI station coordinate may coincide with the geocentric origin. Now, the geodetic reference point was moved to Westford (US). In spite of these definitions, there is still a difference between the VLBI coordinate systems such as in CDP and in IRIS.

The original point of the VLBI terrestrial frame is, in principle, arbitrary according to Eq.(7), because a baseline vector is a relative position between two stations. Hence the two terrestrial coordinates in Fig.10,  $(U_0, V_0, W_0)$  and  $(U, V, W)$  are equivalent to each other for VLBI. Thereby

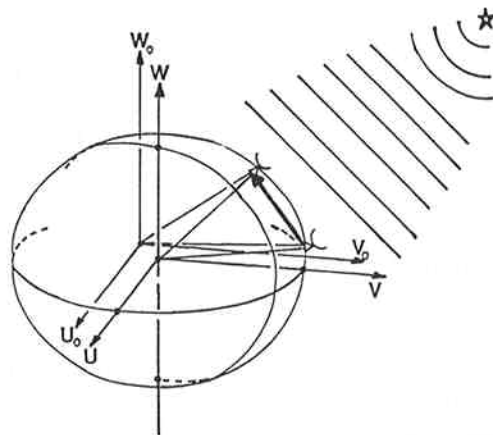


Fig. 10 Two equivalent terrestrial coordinate system in VLBI.

large systematic offsets in station coordinates may be induced between the station catalogs of different programs. Furthermore, the source positions could be systematically different if the adopted models of precession and nutation are different in each analysis system. In fact, source and station catalogs have been developed independently by some VLBI groups. Though they are selfconsistent in each system, it is very important to take both source and station coordinates from only one catalog for consistent data analysis.

### 3. K-3 VLBI Software System Development for Global Geodesy and the Earth Rotation Monitoring

A large K-3 VLBI system for global geodesy and ERP determination, was developed to carry out international VLBI experiments. The implemented system consists of K-3 hardware and software<sup>(18)</sup>. The details of the K-3 hardware system were described in the special issue of 'Review of the Radio Research Laboratories (1984)'. K-3 VLBI software was developed on a newly designed K-3 data base management system<sup>(19)</sup>, having consistency with the entire K-3 hardware system in addition to having compatibility with the Mark III system<sup>(20)</sup>. The outline and functions of the K-3 software system are described here.

There are four specific features in the K-3 software system. First, fundamental data in a data base can be accessed from all the subsystems, which ensures data integrity. Thus, no inconsistent data set is made. Secondly, the software is interactive, while the interactive command sequence can be also executed with automatic batch operation in every K-3 software system. Thirdly, all the physical models and fundamental catalogs are based on the J2000.0 system. Furthermore, the compatibility of data format with Mark III is taken into account regarding the schedule file and the data base tapes as well as raw-data tapes.

Many kinds of data items are produced by VLBI experiments. Even after data reduction the number of data items is still large. Stored data in the disk increases rapidly with the frequency of the experiments and the number of baselines. Furthermore, physical and mathematical constants to be used in the VLBI software are also stored in the data base. Hence a data management capability is required for the total VLBI software system. By making use of the IMAGE/1000 data base (Appendix 3) in the HP-1000 computer, K-3 software was developed to have data integrity and quick data access using a hashing algorithm (Appendix 4).

A data base system introduced to the Mark III software in the United States is the first attempt for VLBI use. It is, however, used only in the data analysis, while VLBI data is commonly used from scheduling to data analysis. Therefore, a data base management system was introduced to the entire K-3 VLBI system for consistent data use. The K-3 software system was developed following the data base system design<sup>(19)</sup> by a special development group. The data base management system is as important to the K-3 software subsystems as the IEEE-488 bus control is to the K-3 hardware devices.

#### 3.1 Software-system Structure

Since the VLBI technique is applied to global geodesy and astronomy, the data value lasts a long time, and it should be accessible to any researcher. Hence the data base management system is one of the best ways to handle a considerable number of VLBI data. The K-3 VLBI software system is designed as illustrated in Fig.11. This system was developed by a special team in Kashima led by Yoshino. First the data base handler system (KASTL) is described. Then, an

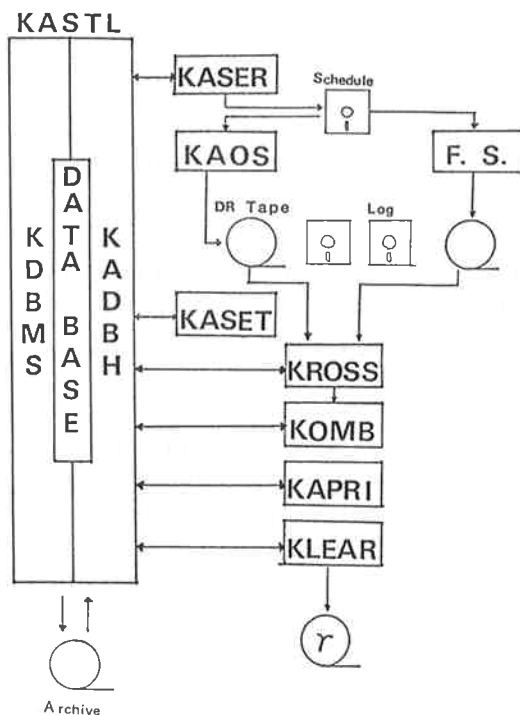


Fig. 11 K-3 VLBI software system.

outline of the scheduling software (KASER), the automatic operation software (KAOS) and the data reduction software (KROSS, KOMB) are described. Then *a priori* value calculation software (KAPRI), and parameter estimation software (KLEAR), are also described.

Before starting a VLBI experiment, a schedule is created interactively using KASER, which has K-3 data base access utility, and also an automatic-scheduling utility. Then a VLBI experiment is carried out automatically by KAOS following the schedule file. Only KAOS software does not have data base access capability because the data and parameters for hardware control are taken from the schedule file. After the experiment, the data area, in which the experiment data is to be written, is created in the data base according to the schedule file and logs of each station through KASET software. KASET also sets the Earth rotation parameters around the experiment date as *a priori* value. Then KROSS produces the correlation data file by controlling the data recorder and correlator. KROSS accesses the data base to make a control file and to set the correlation results into the data base. A precise fringe search with two dimensional FFT computations is made by KOMB to have the final delay and delay rate. Final results are stored in a data base. The delay and delay rate for observations are fixed here. KAPRI calculates the delay and delay rate contributions of the physical effects and their partial derivatives according to the models as *a priori* values for data analysis. They are to be put into the data base. Finally, KLEAR gets the KOMB output (O:observed data) and KAPRI output (C: *a priori* data). Then the parameters are adjusted using a delay and delay rate difference (O-C). Since the Mark III data base format is most popular as the VLBI data format, a data base conversion utility between K-3 and Mark III is developed. Thereby it is also possible to use Mark III analysis software.

### 3.2 Data Base Management System

An easy data access tool was developed at NASA as one of the Mark III VLBI systems<sup>(12)</sup> because VLBI data is large and frequently accessed. Thus the update of VLBI software became independent of the data base.

The design of the data base structure and the data handler is most important to introduce the data base management system. There is no fixed way to design the best data base schema, however.

The data base is one of the projections of the real world. A logical data structure can be seen by grouping the several hundred VLBI terms. Thus, the data item is classified into some groups, where the physical meaning and the occurrence are marked. A group of data ensembles is combined along the flow of data reduction and analysis. There are two types of data in a VLBI data base. One is the data such as observables and constants which do not change. The other is the data which are used only as an index. Both are important for reduction and analysis of the VLBI. Then, each data group is linked from the physical meaning as shown in Fig. 12<sup>(19)</sup>. When designing the data structure, not only the physical meaning but the data producing factor has to be taken into account, because it determines the required size of the data set size and its disk area. The data producing factor of each data set is listed in Table 1. The difference of the K-3 and Mark III data

**Table 1 Main factors of data producing**

(Producing Factor)	( Example )
Experiment	Experiment code, Number of Observation
Observation	Delay, Observation Start Time
Station	Name of Station, Station Position
Baseline	Delay, Ionospheric Delay Correction
Constants	Astronomical and Mathematical Constants
Estimation	Date of Estimation, Baseline Length
Frequency	Receiving Band, Receiving Band Width
Day	UT1, Pole Position
Raw Tape	Tape Number, Name of Station
KROSS Run	Number of Processing, Output file name
KOMB Run	Delay, Fringe Amplitude