

### 3.4.2 REAL-TIME CORRELATION PROCESSING CONTROL SOFTWARE

By

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#### ABSTRACT

The Asynchronous data Transfer Mode (ATM) is capable of transferring a huge amount of data at high speed. The high speed data transfer realized real-time VLBI and it enabled farther automation of the VLBI system. Correlation processing has to work at the same time with observations, and it is also needed to work stably without operators in real-time VLBI. Because troubles of correlation processing directly leads to a loss of observed data. The Real-time KANameishi data processing Togo Software (RKATS) was developed to manage the real-time correlation process automatically, and stably. The Automatic Fringe Search (AFS) function and Dynamic Clock Correction (DCC) function are introduced for the automated stable processing. An overview of the real-time correlation system and the features of the RKATS is presented in this paper.

**Keywords:** ATM network, VLBI, GUI, Bandwidth synthesis, Mark-III database

#### 1. Introduction

The Asynchronous data Transfer Mode (ATM) network was installed in the Key Stone Project (KSP) system as a test-bed for a high speed data transfer experiment in collaboration with Nippon Telegraph and Telephone Co. Ltd (NTT). The high data transfer rate of the ATM network enabled real-time VLBI, in which the correlation process is performed at the same time with observations. The advantages of real-time VLBI are pointed out below:

1. Wide band-width observation. In the case of conventional tape-based VLBI system, the total band width of data processing is limited by the recording rate to magnetic tapes. Direct data connection between observation stations and the correlation center can overcome the limitation.
2. Quick output of analysis data. In conventional tape-based VLBI system, the output of baseline analysis is delayed at least two days due to the need to transport magnetic tapes and to play them back as part of the correlation processing. These two processes are skipped when real-time VLBI is used and the baseline analysis results can be obtained within half an hour after the last observation.
3. Fully automated operation. An operator is needed to transport the tapes and set them up for correlation in the tape-based VLBI system. Real-time VLBI with optical fiber network enables the transportation and the correlation set-up procedure to be done automatically.
4. Real-time system checking. Performance testing of VLBI observation stations can be done in real time.

The Real-time VLBI correlation process requires some special functions. Since re-processing of the data is impossible and operators are not always VLBI specialists, a stable and fully automatic process is desired. A Real-time KANameishi data processing Togo Software (RKATS) was developed to provide fully automatic VLBI data reduction procedure management. This paper

describes the operating functions and environment of the RKATS. In the next section, hardware and software components are described. In section 3 software specification is explained. Notable features of the RKATS are introduced in section 4. The RKATS is developed using the KATS<sup>(1)</sup> base and a similar graphical user interface (GUI), directory structures, and files are used as the KATS. Therefore, the figures for the GUI and the detailed contents of each file is omitted from this paper.

#### 2. Real-time VLBI Correlation System

##### 2.1 Hardware components

Fig. 1 shows the real-time VLBI correlation system used in the KSP. The correlation system consists of the hardware components described below. Some equipment are commonly used in both real-time and tape-based system. Details of these components are described in the paper by Kiuchi et al.<sup>(1)</sup>, and devices especially developed for real-time system are explained in the paper by Kiuchi et al.<sup>(2)</sup>. They are briefly reviewed here by components of the correlation system.

**ATM data receiver:** The data from four stations each operating at 256Mbps are transferred through the ATM in many small packets. The packets of original data are re-composed by the ATM receiver at the correlation center. This device recovers packets lost and misdelivered.

**Real-time VLBI interface:** This equipment has a buffer to absorb transmission delay and jitter. Its outputs are the synchronized data of the four stations. The output data is in the same format as the recorder/play-back unit.

**Output interface(DFC-2200):** This device is the same as the one used in the tape-based system. The output interface receives the synchronized data of four stations from the real-time interface, and output them with appropriate delays added for correlation processing. This is controlled by the correlator controller.

**Correlators:** Six single baseline correlators of the type

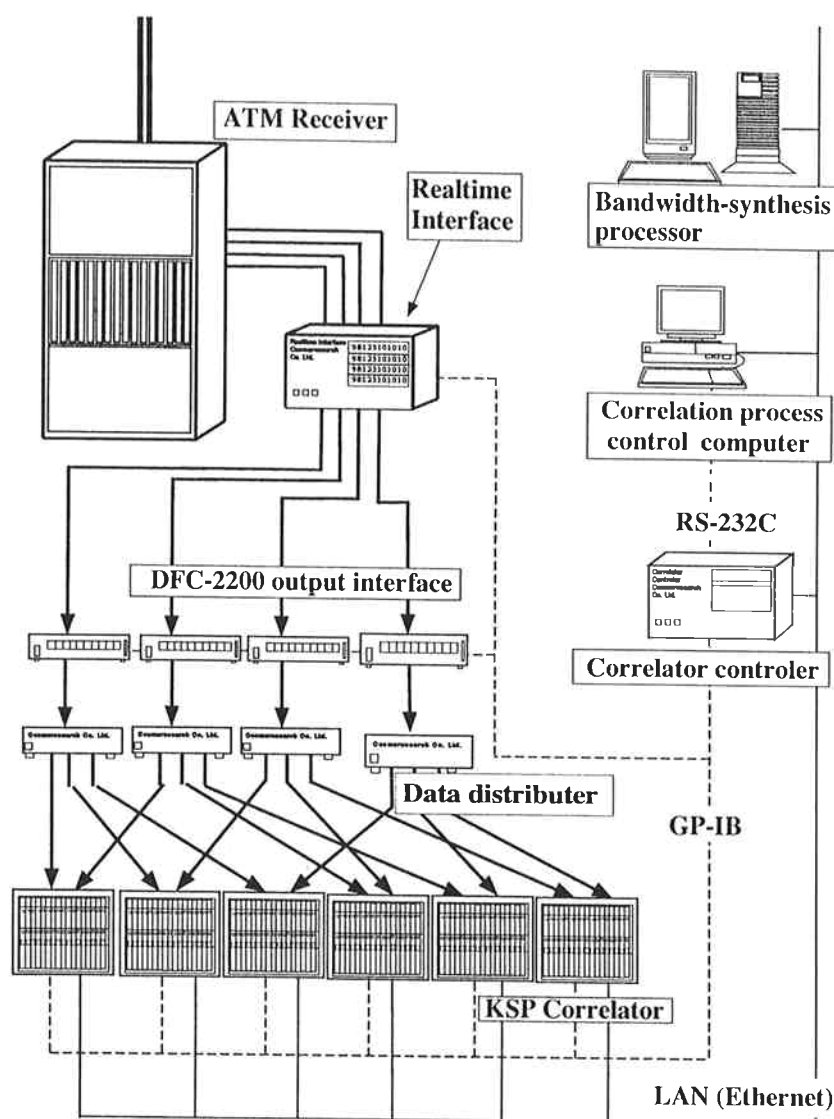


Fig. 1 KSP VLBI Real-time correlation system

used in the tape-based system are connected to a local area network (LAN) and the output data are transferred to hard disk of a Correlation Processing Control Computer (CPCC) through the LAN.

**Correlator controller (CC):** This hardware is also used in the tape-based system, but the software is slightly different. The CC communicates with the RKATS (CPCC) using a RS-232C for receiving command instructions and sending system status information. The CC controls the real-time VLBI interface, the output interfaces, and the correlators via a GP-IB bus, and then performs the correlation process.

**Correlation process control computer (CPCC):** This is the workstation on which the RKATS runs. A HP9000/745i or HP9000/J210 (HP-UX 10.10) is used for the this work. The CPCC is connected to the CC via the RS-232C cable and to the LAN. The computer works as a PC-NFS server and receives output data from the

correlators through the LAN.

**Bandwidth-synthesis processor (BWSP):** The function and hardware is exactly the same as in the tape-based system.<sup>(3)</sup> The BWSPs and CPCC have a large hard disk capacity for correlation output data storage. The disks are shared with each other via the LAN.

## 2.2 Software components

**Correlation process control software "RKATS":** The RKATS manages the data reduction process in the KSP-VLBI experiment. This software runs all the time and automatically chooses a schedule file for correlation processing. For every observations, the RKATS sends a correlation start signal to the CC via the RS-232C. Information necessary for correlation processing is passed to the CC through the LAN. Then the bandwidth synthesis software (KOMB) is invoked for each feed of correlation output data. After all the correlation processes have finished, the

Mark-III database is created (db.pl). The flow of these processes is managed by the RKATS.

Besides schedule file is chosen automatically, particular schedule can be chosen manually, and several process parameters can be modified from the GUI.

Bandwidth synthesis software "KOMB": This is the same software as is used in tape-based system.<sup>(3)</sup> The data is integrated in frequency and time direction and exact observed delay is derived by this software. More detail of the KOMB is described in the paper by Kondo et al.<sup>(4)</sup>

Database creation software (db.pl): This is the same with that of tape-based system<sup>(3)</sup>. The observed time delays and delay rates are stored in the Mark-III database system, then the automatic baseline analysis software is invoked and the result is registered on WWW home page. A detailed description of the software is given in the paper by Koyama et al.<sup>(5)</sup>

### 3. RKATS Specifications

#### 3.1 Operations and flow

The RKATS is designed for fully automatic operation. An operator need not set-up the correlation process when the normal automatic operation mode is used. The flow of automatic processing is as follows:

1. Schedule file selection: The RKATS runs constantly and checks the current time and schedule file in the local (/usr/local/kats/data/skd) and remote host directory, which is written in the resource file (see subsection 3.3.4), every several minutes. The VLBI schedule file name has to be in the format of 'ksyyddd.skd', where yy: year, ddd: total days of the year. If a schedule file name matches with the current date, the RKATS reads the schedule and saves the parameters into internal files (see subsection 3.3.3).
2. Clock parameter file transfer: The RKATS searches for the clock parameter files in the remote hosts at the observation stations and transfers the files to the local directory by the File Transport Protocol (FTP). If the files for some stations are not found, the parameters used in the last correlation process are applied. A clock parameter is the time difference between the clock of the VLBI formatter and the coordinated universal time (UTC). This data is recorded every minute into clock parameter file at each observation station. These parameters are important to synchronise the data from four stations for correlation processing.
3. Correlation process: The RKATS sends the correlation start signal to the CC with each observation. The CC performs the correlation process with the output interfaces, the real-time VLBI interface, and the correlators. The information necessary for the process is provided by the RKATS. The correlation output data is transferred to the CPCC through the LAN, then the bandwidth synthesis is applied on the data. This procedure is repeated from one observation to another until the end of an experiment.
4. Automatic fringe search and dynamic clock

correction: To avoid the loss of fringe detection in the automatic real-time correlation system, the automatic fringe search (AFS) and dynamic clock correction (DCC) were implemented in the RKATS (see subsection 4.2.). If fringe is not detected on selected strong sources, the RKATS switches the correlation mode to the fringe search mode. The 32 lags of each 16 correlation unit are aligned in a series and one channel of data is distributed to the 16 correlation units. If fringe is detected in this expanded 512 lag window, the clock parameter is adjusted so that the fringe will appear at the center of the lag window. Then the correlation mode is switched to the normal mode.

Dynamic clock correction operates in the normal correlation mode to keep the fringe at the center of the lags by adjusting the clock parameters of the observation stations.

These function are switched on and off by manual setting (see subsection 3.2).

5. Bandwidth synthesis: Bandwidth synthesis is invoked for every observation. The correlation output data is integrated in time and frequency direction (16 channels) and the precise propagation delay and its rate of change are obtained.
6. Mark-III database creation and baseline analysis: When all observation data in an experiment are processed, the observed delay data and their rates of change are extracted from KOMB output files and stored in the Mark-III database system. Then the baseline analysis software runs and the solution is added to KSP home page automatically.
7. Waiting for the experiment schedule of the next day: The RKATS returns to a state of waiting for the observation schedule of the next day.

#### 3.2 Manual setting of RKATS

Some modification of the correlation processing parameters or a choice of observation schedule other than the routine work schedule is possible by using the manual setting window of the RKATS.

Schedule selection: If it is necessary to operate a schedule file other than the routine work schedule file named "ksyyddd.skd", manual schedule selection is possible from the "Correlation Setting" → "Schedule Selection" window. Schedule file transportation from remote host computer is also available from "Correlation Setting" → "Schedule Selection" → "File transportation" window. Preliminarily set-up of the remote host name and login parameters should be written in the resource file. These procedures are the same as those of tape-based system.<sup>(3)</sup>

Bandwidth Synthesis: The choice of frequency band to be processed whether "S/X", "S", or "X" is available from the "Bandwidth synthesis setting" button (see Fig. 6 left of the paper by Sekido et al.<sup>(3)</sup>).

AFS/DCC: The parameters of the "Fringe detection SNR" for the AFS, the "Fringe detection SNR" for the DCC, the "Detection Ratio limit", and the "Sample number" can be modified on the "Fringe Search/Dynamic Clock Correction Setting" window (

see Fig. 6 of the paper by Sekido et al.<sup>(4)</sup>). The "Fringe Search Source list" can be modified by editing the \$SOURCE term in the SRCH\_INF file. More detail of the AFS/DCC is described in the later section, "Automatic Fringe Search and Dynamic Clock Correction".

**ERP/Clock/PP:** The earth rotation parameters, the parameter period, and the clock parameter of each station can be modified on the "ERP/CLOCK/PP parameter setting" window (see Fig. 10 of the paper by Sekido et al.<sup>(3)</sup>).

**Data Line Connection and KOMB HOST information:** The RKATS needs the information of the actual data line connecting from the ATM receiver to the correlators. This information should be registered at the time of installation. It is set from the "Data Line Connection/KOMB HOST Setting" window (see Fig. 8 of the paper by Sekido et al.<sup>(3)</sup>).

The KOMB processes are performed by using multiple workstations simultaneously. The host names of workstations on which KOMB process is done are also set in the same window.

**Baseline selection** The sets of baselines are selectable in the "Baseline Selection" window (see Fig. 9 of the paper by Sekido et al.<sup>(3)</sup>). Ordinarily all the baselines are selected. The selection function is used when a certain baseline is not wanted.

### 3.3 Files and directories

#### 3.3.1 Directory tree

The RKATS runs on the same directory as the KATS<sup>(3)</sup>. The "bin/" directory contains executable files. The "data/" directory consists of a schedule file directory: "skd/", a log file directory: "log/", an internal file directory: "data/", a process history file directory: "prc/", and a temporary file directory: "temp/". The role of each file is described in the next section.

Output data from a correlator and KOMB are written under the directory as "/<host-name>/vlbidata<number>/<data type>/<experiment code>". The "<host-name>" is the name of workstation where the hard disk is mounted. The "<number>" is the number of hard disk of the workstation. The "<data type>" is kross: correlation output, or komb: KOMB output. An example of a directory path name is "/komb1/vlbidata3/kross/KS98171/". The HP9000/J210 workstations "komb1", "komb2" and the HP9000/735 and HP9000/745 workstations "washi" and "eve", respectively, are connected to the LAN. They have large capacity of hard disks and share them with each other via the LAN. This rule of the directory path names is used to access the correlation data transparently from any of the workstations. It is important for parallel processing of the KOMB with the multiple workstations.

#### 3.3.2 RKATS input files

The RKATS gets the necessary information for the correlation process from the schedule file, the clock files, and the log files. The KSP VLBI schedule format is based on the standard VLBI schedule format.<sup>(6)</sup> It must contain the terms \$EXPER, \$SKED, \$SOURCES, \$STATIONS, and \$CODES, which are the same as used

in the tape-based system. A clock file contains the time difference between the clock of the VLBI input interface and the UTC at one observation station. The file format is the same with log file and the data (VLBI input interface minus UTC) is written after the label of "/TD/" in micro seconds. Log files must contain the following terms:

**/WX/** The temperature, air pressure, and humidity at the station. This meteorological data needs to be updated frequently, at least several times per hour. This data is used for atmospheric delay calibration and are stored in a Mark-III database together with the VLBI observation data.

**/CABLE/** Cable calibration data is stored in the Mark-III database and used to correct changes in the cable length in the data analysis.

#### 3.3.3 Internal files

The RKATS uses the following internal files to memorise the current processing information. The contents of each file are the same as that of the KATS, except for CLK\_CRCT.

**COR\_BASE** A file to memorise the correlator-baseline assignment information and the process flag.

**COR\_INF** This file is made by collecting information from other internal files with every observation. The CC refers to it for the correlation process.

**COR\_MSG** Error or warning messages are written by the CC if any troubles occurred.

**CRSS\_PAR** The parameters and flags necessary for correlation processing are written in this file.

**CTL\_INF** The path name of the internal files are listed. This file is referred to by the CC through the LAN.

**DB\_INF** This file is used for preparing the Mark-III database. It is used by db.pl.

**ERP\_INF** This file contains the Earth rotation parameters(ERP). It is automatically updated by a program called TAKEMIKAZUCHI<sup>(5)</sup> when a new ERP is delivered from the IERS by e-mail.

**KHSC\_ADR** This file stores GP-IB hardware addresses of equipment and referred by the CC.

**KOMB\_HOST** Some candidates of the KOMB execution host are memorised. This file is used at the "Data Line Connection/KOMB Host Setting" (see the item in 3.2 "Manual Set of RKATS").

**KOMB\_SET** This memorises the KOMB option.

**KROSS\_NM** The cross correlation output data file has a sequential number such as "K12345". The current serial number is memorised in this file.

**MAIL\_ADR** This contains the mail addresses where error or warning messages should be sent when any trouble occurs.

**OBS\_INF** The observation number, source name, and observation start time extracted from the schedule file are written in this file.

**REC\_COR** A file to register information about the cable connections from the ATM outputs to the correlators. This file is modified in the "Data Line Connection/KOMB Host Setting" window.

**REC\_STAT** List of assignments from the observation

stations to the ATM receiver outputs. This can be modified from the "Station Assignment" window.

**SRCH\_INF** The parameters for fringe search are memorised in this file. Following the label of \$ORDER, station names are listed in order of priority for determining the clock parameter. The clock parameter of a station with lower order priority is changed during the fringe search process. The names of sources with strong flux, which are used for fringe search are listed under the \$SOURCE term. The term \$JDG\_LVL is used to signify the SNR threshold of the AFS function.

**PRC file** The correlation and KOMB process histories are recorded in this file, which is located in the prc directory.

**CLK\_CRCT** This file is newly implemented in the RKATS. it contains the status of the DCC "ON" or "OFF", the "Fringe Detection SNR" for the DCC, the "Detection Ratio limit", and the "Sample number" for calculating the fringe detection ratio.

### 3.3.4 Resource file

The RKATS uses an X-window system resource file as a set-up file. If the RKATS is invoked with argument, that is taken as the resource file; otherwise "\$HOME/.Xdefaults-<host name>" is used. The items in the resource file are the same as those of the KATS. The full resource list is given in the RKATS manual.<sup>(7)</sup>

## 4. Features of the RKATS

### 4.1 Fully automated real-time correlation processing

The most notable feature of the RKATS is fully automated correlation processing, which was impossible in previous tape-based system. It is realized by real-time data transportation from distant observation stations to the correlation center. The observed data is automatically fed to correlators without help from operators. There is a strong requirement for a real-time correlation system that is highly stable and has robust fringe detection. Because the loss of fringe during the correlation process directly leads to loss of data. Additionally, operator's support cannot be expected all the time during the observation. Hence the RKATS was developed with

special attention to avoid "hung up". And the AFS and the DCC functions were implemented to keep fringes within the lag windows. The results of combining an automatic observation system,<sup>(8)</sup> automatic baseline analysis,<sup>(5)</sup> and a computer network among them achieved the automated VLBI measurement.

### 4.2 Automatic fringe search and dynamic clock correction

The observation and correlation process is performed automatically without an operator. A mistake in the of correlation process directly leads to the loss of experiment data, since observed data is not recorded. To avoid the loss of fringe detection in the AFS and DCC functions are introduced in the RKATS.

#### 4.2.1 Dynamic clock correction function

Dynamic clock correction (DCC) corrects the clock parameters during "normal" mode correlation. When the current observing source is one of the sources in the "Fringe Search Source list", then fringe detection operates. If the observed SNR is larger than the "Fringe Detection SNR", a deviation of fringe position from center of lags is corrected by modifying the corresponding stations' clock parameters. An example of the result of this function is shown in Fig. 2 (left). The clock parameter of Kashima station is fixed and the other three stations' (Koganei, Miura, Tateyama) clock offsets are adjusted by the DCC function. The variation of the clock parameter is less than 0.1 micro sec. The function of the DCC can be switched on and off from the "Dynamic Clock Correction" button in the "Correlation Process Setting" window (see Fig. 6 of the paper by Sekido et al.<sup>(3)</sup>).

#### 4.2.2 Automatic fringe search function

A ratio of number of observations with fringe and the numbers without one is used to change correlation mode. If the ratio become lower than "Detection Ratio limit", correlation mode is switched from the "Normal" to the "Fringe Search" mode. The maximum number of observations to calculate the fringe detection ratio is limited by a parameter "Sample number". In the fringe search mode, data of one frequency channel (Common channel: see the internal file SRCH\_INF) is distributed

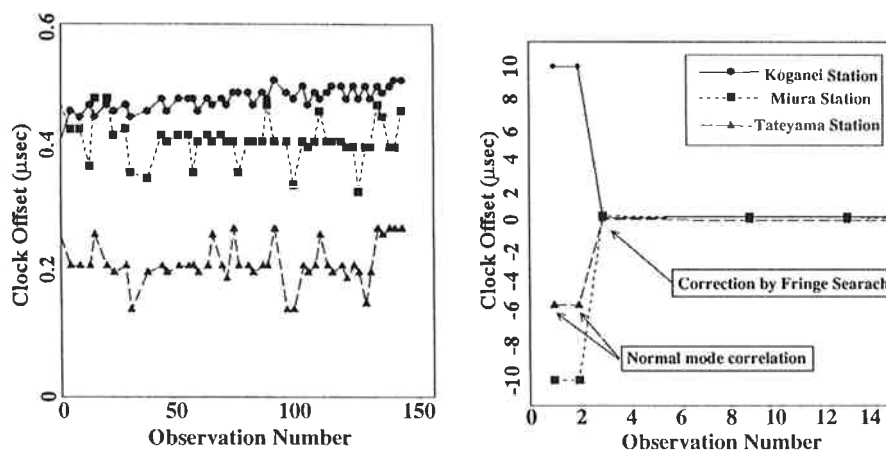


Fig. 2 A test result of the DCC (left) and the AFS (right) functions

to all the other 15 correlation units and the 32 lags of each unit are aligned in a series to expand the lag window. When the source is one of the those in the "Fringe Search Source list" and the SNR is larger than the "Fringe detection SNR" for a fringe search, the data is judged as a fringe was detected. Then the clock parameters of each station are adjusted so that the fringe will appear at the center of the lags, and the correlation mode is switched to the "Normal" mode again. An example of the AFS clock offset correction is plotted in Fig. 2 (right). Before this test experiment, the clock parameters of the Koganei, Miura, Tateyama stations were artificially biased with an offset of 10 micro sec., - 10 micro sec., and - 6 micro sec., respectively. Kashima station was set as the highest order in the \$ORDER section of the SRCH\_INF file, then the clock of Kashima was regarded as a reference. Fig. 2 clearly shows that the other stations' clock offsets were adjusted after the fringe search.

### 5. Summary

The RKATS was developed for managing real-time VLBI correlation processing. The AFS and the DCC functions have been shown to effectively overcome the problem of wrong clock parameters. Fully automated and stable correlation processing has been achieved and the RKATS is contributing to the monitoring crustal deformations around the metropolitan area.

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