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III. VLBI SYSTEM

III.3 K-3 AND K-4 VLBI DATA RECORDERS

By
Shin'ichi HAMA and Hitoshi KIUCHI

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ABSTRACT

The Communications Research Laboratory (CRL), Japan, developed a VLBI data recorder, called K-3, which is compatible with the Mk-III VLBI data recorder but is controlled by GP-IB as are other K-3 devices. The K-3 recorder has been used for data acquisition and correlation processing since 1984. Although the recording density of the K-3 (or Mk-III) VLBI data recorder is as high as 100 Gbit per tape, almost 30 large expensive tapes are required for an ordinary geodetic experiment. Therefore, a great effort was made to increase the recording density. In Japan, the K-4 VLBI data recorder was developed jointly by CRL and SONY Co., and in the United States the Mk-IIIa VLBI data recorder was developed by Haystack Observatory using a different approach to achieving high density.

The K-4 system was used for the first time for a domestic VLBI experiment in June 1989[1] and completed correlation processing satisfactorily, K-4 is now used on a regular basis in Japan.

The K-3a VLBI data recorder, which is a modified K-3 data recorder compatible with the Mk-IIIa VLBI data recorder, has also been used regularly since 1986 for the Crustal Dynamics Project (CDP) VLBI experiments supported by NASA.

This paper introduces and compares these data recorders. The K-4 VLBI data recorder is explained in detail except for the input interface which is covered by another paper as part of the data acquisition system[1].

1. Introduction

The K-3 data recorder is a modified Honeywell M-96 data recorder which uses 14 inch open reel tapes to record 100 Gbit of raw data per tape with a density of 33.3 kbpi on 28 tracks[2]. In spite of the high recording density, almost 30 tapes are required per 24 hour ordinary geodetic VLBI experiment.

As the tape is very heavy and expensive, the total price,transportation costs, and labor costs are big problem for VLBI.

Therefore, a number of attempts were made to increase the density of recording; e.g. increasing the number of tracks using the current VLBI data recorder[3], or using helical scan techniques.

The K-4 VLBI data recording system developed by CRL uses the helical scan technique. It is based on a SONY broadcasting VCR (Video Cassette Recorder). It includes special input and output interfaces to make it compatible with the earlier K-3 (or Mk-III) VLBI data recorder. Data is recorded on high-density lightweight cassette tapes. This remarkably improves the transportation and management of the tapes. Furthermore tape synchronization during correlation processing has been greatly simplified by using the phase synchronization function available on the broadcasting VCR.

The Mk-IIIa VLBI data recorder developed by Haystack Observatory in the USA uses a different technique. It is based on the earlier Mk-III VLBI data recorder with an improved headstack. Tapes are almost same as for the Mk-III VLBI recorder but recording density has been increased up to 12 times.

2. K-3 Data Recorder

In VLBI, the tapes recorded at many stations have to be collected at a correlation station for synchronized replay. A Honeywell M-96 wideband recorder was modified to make it compatible with the Mk-III system in the USA. As the M-96 is a general purpose recorder, it was necessary to modify it for VLBI use. CRL used the original transportation mechanism and magnetic heads but modified the electronics for recording, replay and control. Figure 1 is the block diagram of the K-3 data recorder. As with other K-3 devices, GP-IB was used for control in preference to the MAT (Microprocessored ASCII Transceiver)(4) that is used for the Mk-III system. The specifications of the K-3 data recorder are shown in Table 6 but its details are covered by another paper(2).

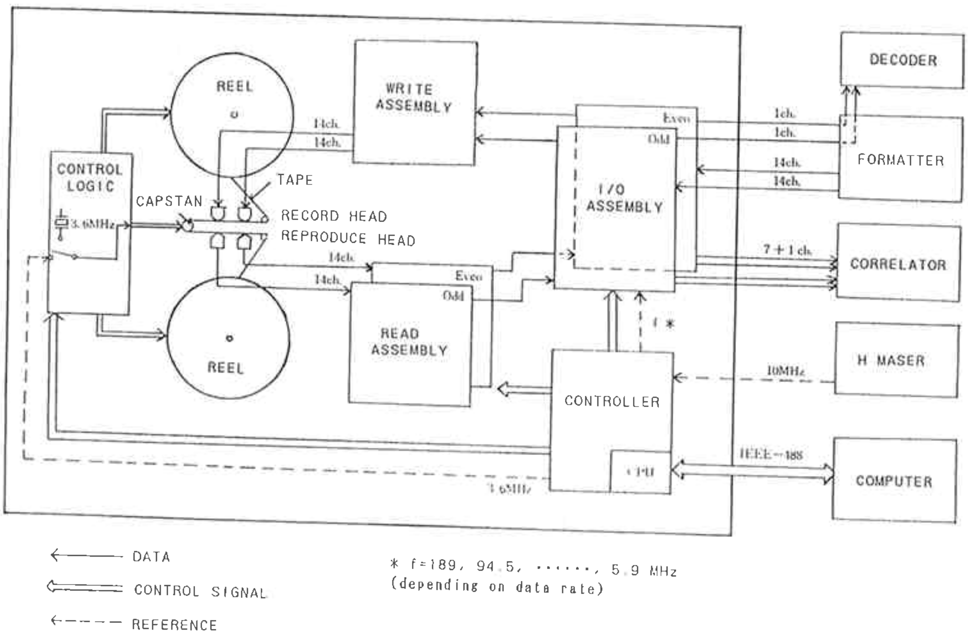

Fig. 1 Block diagram of K-3 recorder.

The K-3 data recorders have been used for data acquisition and correlation processing since 1984. They have also been used by the GSI (Geographical Survey Institute, Japan) and the ISAS (Institute of Space and Astronautical Science, Japan) as VLBI data acquisition recorders.

3. K-4 Data Recording System

Figure 2 shows the front panels of the K-4 recording system. It consists of a data recorder, an input interface, and an output interface. The data recorder and the output interface are explained in this section. The input interface is explained in the other paper[(1)] of this issue.

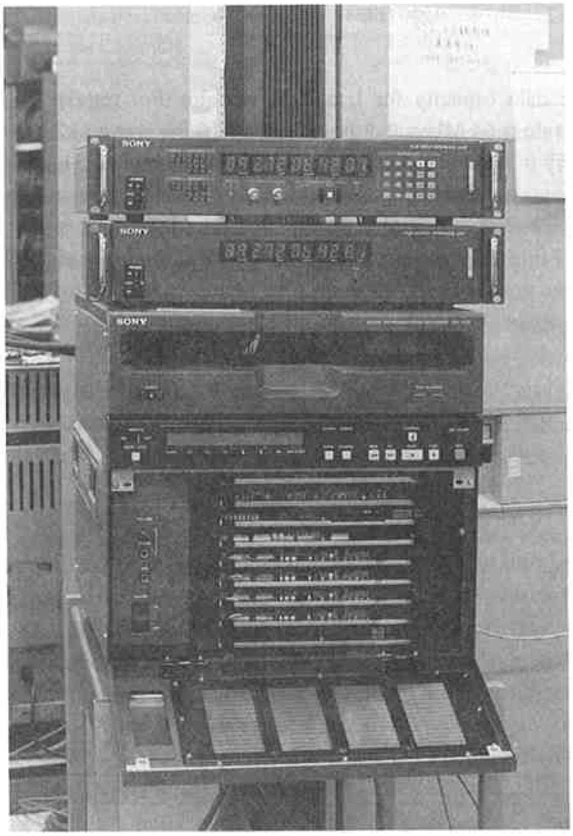

Fig. 2 Front panels of K-4 VLBI recording system.

3.1 Data Recorder

Tapes for the K-4 data recorder are the commercially available D-l type[(5)] VCR cassette tapes. There are three sizes of cassette tape but the large (L) size is normally used for regular VLBI experiments. The medium (M) and small (S) sizes are also sometimes used. The K-4 data recorder automatically recognizes the cassette size and rejects D2 type metal tapes which look like D-l tapes but are not suitable for the K-4 data recorder. The regular tape thickness is 16 μm, but thinner 13 μm tape is also available. This enables much more data to be recorded. Table 1 shows the relation between

Table 1 Data and Capacity of K-4 tape

bit rate [Mb/s]	capacity (minute) cassette L	capacity (minute) cassette M	tape speed [mm/s]
256	50 (61)	22 (27)	423.8
128	100 (123)	45 (55)	211.9
64	200 (247)	90 (111)	105.9
32	400 (494)	180 (222)	53.0
16	800 (989)	360 (445)	26.5
10.7	1200 (1484)	540 (668)	17.7

the data rate and the data capacity for L and M cassette. For regular 24 hour geodetic VLBI experiments, the data rate is 64 Mbps and the recording time is around 12 hours. The L size cassette has to be changed every 6-7 hours. However, an automatic cassette tape loader can be used to enable operator-free experiments to be made, thus considerably reducing correlation processing labor costs.

Figure 3 shows how data is recorded on the tape. The recording format based on the ID-1(6) standard is shown in Table 2. There is no guard band in K-4 data recorder. Therefore each track is recorded adjacent to the next track to achieve a very high recording density. To avoid crosstalk, the azimuth of tracks are offset alternately.

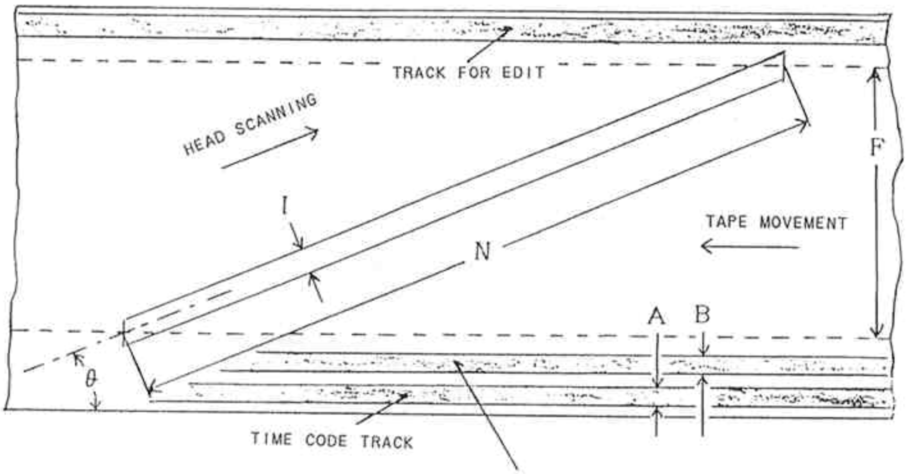

Fig. 3 K-4 Tape Recording Format.

One K-4 data recorder has totally 8 heads, that is four pairs of head, whose azimuths are ±15° each. The tape width is 19.010 mm and its acceptable width fluctuation is 6 μmp-p. There are no individual erase heads for each track. Instead, there is one wide erase head across the tape width.

The K-4 data recorder is used with an input interface for data acquisition and with an output interface for correlation processing. The recorder is controlled remotely through GP-IB of each interface. The protocol is based on the same rules as the earlier K-3 VLBI data recorder rules.

Table 2 Recording Format of K-4

recording format	ANSI X3B6
error correcting code	Reed-Solomon product
guard band	none (azimuth recording)
A: timecode track	0.5 mm
B: control track	0.5 mm
F: data area	16.0 mm
I: track width	0.045 mm
N: data track length	170.0 mm
θ: track azimuth	5.4005°

Operators therefore easily become familiar with control. Communication between the K-4 data recorder and each interface is through an RS-422.

The bit error rate after correction is 10^{-10} when the original error rate is 10^{-4}. The number of errors from each head can be monitored remotely. VLBI data accepts random error rate up to 10^{-3}. Therefore if the header (including the time, sync word and so on) can be read, the capability of K-4 is far better than required. The recorder can interleave and shuffle data. However these are not necessary for present VLBI data format. Therefore, higher recording density can be achieved by optimizing the error correction for VLBI.

Also the K-4 data recorder has also a convenient function called "preroll", which is used for moving tape to the desired position. It is very useful for synchronizing two or more tapes in correlation processing.

3.2 Output Interface

Figure 4 shows the outline of the output interface and Table 3 shows the specification. The output interface is a signal format converter to make the 8 bit parallel output of the K-4 data recorder compatible with the 16 channel input of the K-3 correlation processor. One output interface corresponds to one K-4 data recorder. As the signal from the recorder does not have parities or the same header as the K-3 signal, this interface can generate and overwrite the header (time code, sync code and AUX code) and parities. It outputs two types of signals, K-3 type after the overwriting (4.5 Mbps/ch.) and K-4 type as recorded (4 Mbps/ch.). The signal level is ECL complimentary, which is compatible with the K-3 (or Mk-III) correlation processor.

When we use two or more pairs of K-4 data recorder and output interface for correlation processing, one pair should be specified as "master" and others are specified as "slave". The tape synchronization function for multi-tapes are mentioned in the next section.

Table 3 Specifications of output interface

size	424 × 88 × 550 mm
weight	13 kg
power consumption	60 W
communication with transport	RS422
communication with host	GP-IB

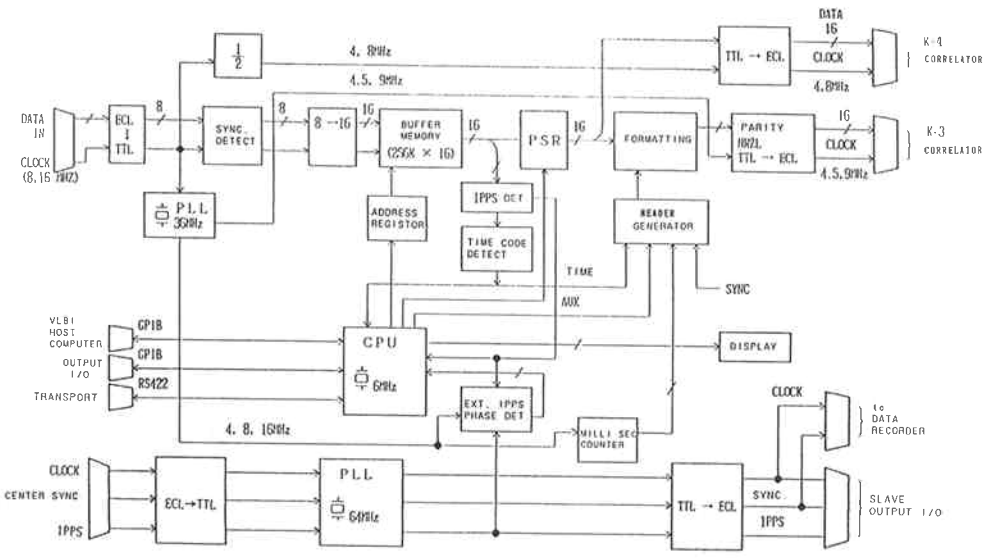

Fig. 4 Block diagram of K-4 Output Interface.

3.3 Tape Synchronization for Correlation

As this recorder was originally designed as a broadcasting VCR, it is able to playback multiple tapes after synchronizing each timing. We made use of this to synchronize VLBI data down to one bit. This makes the hardware and software of K-4 VLBI correlation processing much simpler.

Following the sequence shown in Fig. 5, we can synchronize the slave recorders with the master recorder. This is very simple compared with the complicated procedure of the K-3 (or Mk-III) recorders, particularly for many (3 or more) recorders. There is a difference between synchronization of broadcasting tapes and of VLBI data. Only coincidence is required for the former, while the total of τg (geometrical delay) and clock offset is required for the latter. The total is 40 ms max on the earth, because the clock offset among regular VLBI stations is at most within several μs. The output interface has a 256 kb/ch. buffer memory to set this τg.

The time required for the synchronization greatly depends on the initial error. The tapes synchronize within 10 seconds when the initial sync error is within 0.5 seconds, while it takes nearly 40 seconds when the initial error is several seconds. But knowing the initial error after a trial payback, we can reconsider the synchronizing error to get them synchronized within 10 seconds. The principle is the same even if the number of recorders is three or more. Hence it should be faster than the Mk-IIIa when there are more than two recorders. This time can be improved by modifying the algorithm written in the output interface ROM.

The synchronization program for two K-4 data recorders and for K-4 and K-3 data recorders has already completed and has been used on the regular basis.

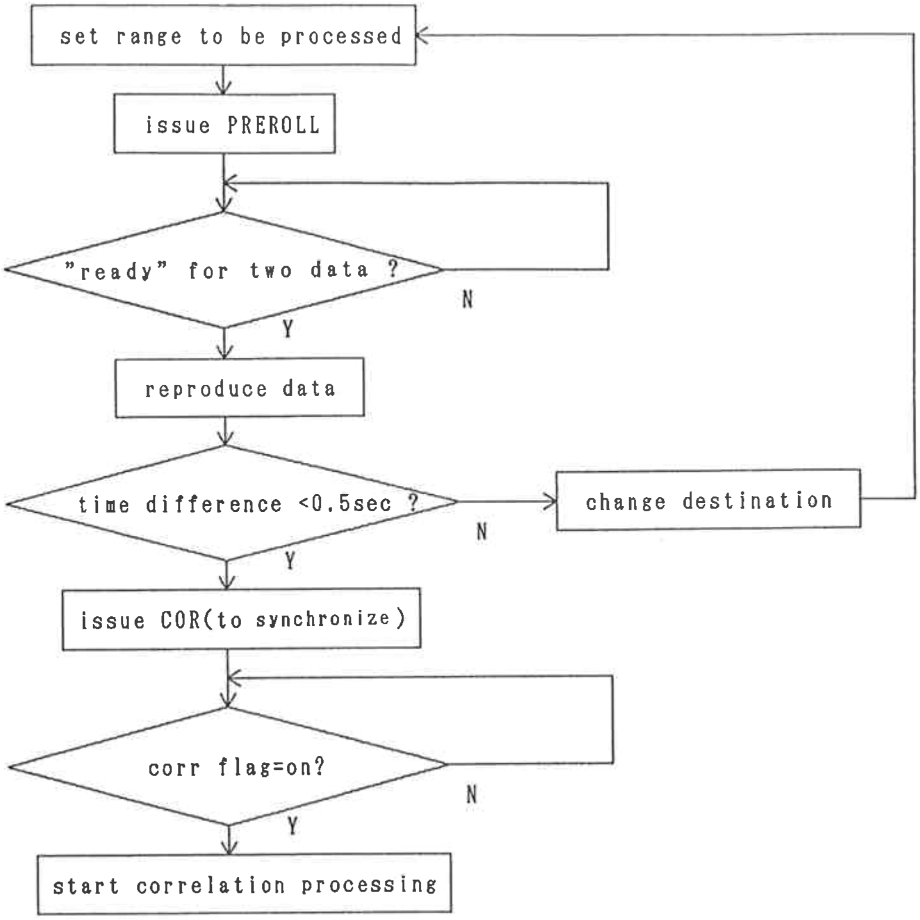

Fig. 5 Procedure for Synchronization.

4. K-3a Data Recorder in Kashima

The high density update system of the Mk-IIIa has been installed on K-3 data recorder. This is composed of a headstack, an inchworm, and an LVDT. This modified recorder is called the K-3a and its data is compatible with Mk-IIIa data. Its operation in Kashima is explained below.

Hinteregger et al. of Haystack Observatory in the USA achieved high density using the standard Honeywell M-96 data recorder. The standard headstack consists of two groups of heads. One group has even heads and the other group has odd ones. Each head is 635 μm thick. On the other hand heads as thin as 40 μm are used in the Mk-IIIa as shown in Fig. 6 and they are moved parallel to the tape width to record many tracks. 14 tracks are initially recorded in the forward direction and 14 tracks in the reverse direction as shown in Fig. 6 (the hatched area means the recorded). Next, the headstack is moved 55 μm parallel to the tape width to record another 14 tracks forward and another 14 reverse.

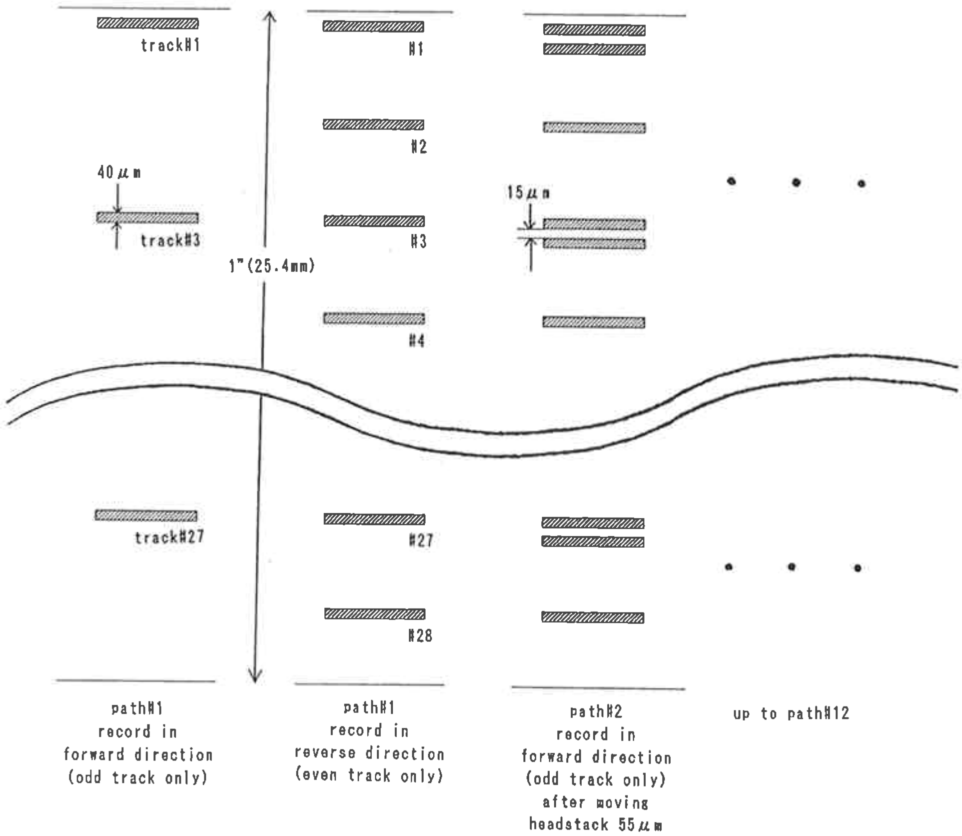

Fig. 6 Procedure for high density recording with K-3a Data Recorder.

By repeating this procedure 12 times, data capacity of the tape is increased by a factor of 12.

The block diagram of the system is shown in Fig. 7. An inchworm(7) made by Burleigh Inc. is used to move the headstack precisely. It consists of a shaft and cylinders which move the shaft in small steps by expansion and contraction. The headstack is fixed on the shaft which is cramped onto the cylinders. The cylinders are made from PZT ($Pb(Zr_xTi_{1-x})O_3$). This is a piezoelectric actuator and its specification is shown in Table 4. It can be positioned with great repeatability by controlling the voltage on the inchworm as it has no structural backlash.

Table 4 Specifications of inchworm

resolution	20 nm
driving range	25 mm
drive power	1.5 kg
speed (fast)	2000 μm/s
(slow)	10 μm/s

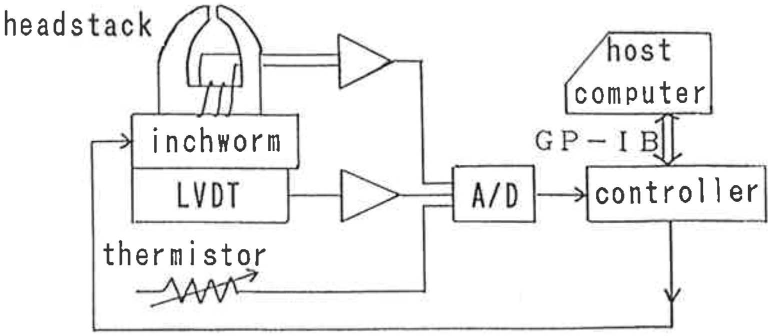

Fig. 7 Block diagram of K-3a Data Recorder.

Table 5 Commands for K-3a recorder.

DIR = FORnnnnn (0 < nnnnn < 65536)	move headstack forward nnnnn × 40 μs
DIR = REVnnnnn (0 < nnnnn < 65536)	move headstack reverse nnnnn × 40 μs
DIR = STP	stop headstack
SPD = FAST (or SLOW)	change the speed of headstack
HDn = ON (or OFF) (n = 1, 2)	enable headstack to be driven
OSCn = ON (or OFF) (n = 1, 2)	enable oscillator of LVDT
TMPn = ? (n = 1, 2)	get temperature of headstack
OUTn = ? (n = 1, 2)	get amplitude of output
LVDn = ? (n = 1, 2)	get output of LVDT

The position of the headstack is measured in each recording path using an LVDT (Linear Voltage Difference Transformer)[8]. Inputting a constant AC produces AC output depending on the position of the core. Its linearity is ±3.1 μm. The position is fed back to control the headstack.

In order to carry out the correlation processing smoothly, the positions of recorded tracks must be same in every VLBI station. Therefore calibration with a standard tape is necessary at the time of initial installation of the headstack. Although the headstack can be moved manually, remote control with a program is needed to record data in experiments or to read data.

The Mk-IIIa data recorder is controlled by MAT through RS-232c. However the control system was modified so that it can be controlled through GP-IB, thus achieving compatibility with other K-3 equipment. Table 5 shows the commands for this system. For example,

DIR = FOR02000

means: move the head forward 40 μs times 2000 units.

Modifications of the headstack (including its control system), preamplifiers and equalizers in the replay circuit were necessary in order to reproduce the low S/N signal. Also high density tape must be used. The Mk-IIIa recorder has been used on a regular basis for international VLBI experiments sponsored by NASA. Figure 8 shows the GP-IB controller (upper box) and the inchworm controller

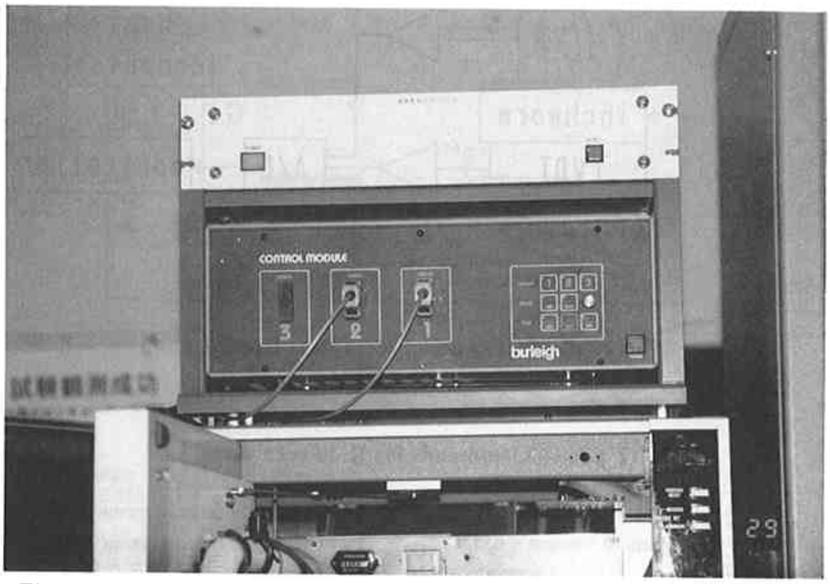

Fig. 8 GP-IB controller and Inchworm controller for K-3a Data Recorder.

Table 6 Comparison of K-3, K-4 and K-3a recorders.

	K-4 (cassette L)	K-3a	K-3
size of recorder	436 × 414 × 656 mm	559 × 2076 × 737 mm	559 × 1650 × 737 mm
weight of recorder	65 kg	250 kg	250 kg
power consumption	450 W	1000 W	1000 W
tape size	206 × 366 × 33 mm	355.6 ϕ × 30 mm	355.6 ϕ × 30 mm
weight of tape	1.37 kg	4.3 kg	4.3 kg
coercivity	68000 A/m	54000 A/m	54000 A/m
track width	45 μm	40 μm	635 μm
bit density	19.6 Mb/in ^{2}	11.2 Mb/in ^{2}	1 Mb/in ^{2}
Capacity/tape	770 Gb (200 min)*	1200 Gb (337 min)	100 Gb (27 min)
error rate	10^{-10}	10^{-4}	10^{-5}
Head	rotary	stationary	stationary
tension	mechanical	vacuum column	vacuum column
tape speed	0.11 m/s	3.43 m/s	3.43 m/s

* for 16 μm thick tape.

(lower box), which are located on the K-3 data recorder rack.

5. Comparison of the Recorders

Table 6 summarizes the features of each recorder. As the K-3 (or Mk-III) is inferior to the Mk-IIIa and K-4 in every respect, the comparison below is between the K-4 and the Mk-IIIa. The advantages of the Mk-IIIa are

(1) Large absolute capacity of each tape.
(2) Used regularly for international VLBI experiments.
(3) Modified standard Mk-III (or K-3) data recorder.

The advantages of the K-4 recorder are

(1) Cassette tape is lighter and more convenient.
(2) Data recorder is light-weight and portable.
(3) Tape speed is much slower, therefore tape transport is more stable.
(4) Simplicity of tape synchronization for correlation processing.
(5) No skill needed for changing tapes (just insert) and data replayed without skill or need for a program.

Generally the advantage of the Mk-IIIa is compatibility with earlier standard VLBI systems, whereas that of the K-4 is compactness. As the Mk-IIIa seems to have established its position for international VLBI experiments sponsored by NASA, we now use the Mk-IIIa for CDP VLBI experiments and use the K-4 for domestic and developmental experiments. However several institutions inside and outside Japan are very interested in the K-4 system and have done some VLBI experiments using the K-4.

The most important advantage of the K-4 is (1) in the above list. Only three or four cassettes are required for each experiment. They are much easier to be processed and mailed than the large heavy open reel tapes used in the Mk-IIIa system.

As Japan lies on the four big plates[9], there is a need to conduct efficient geodetic VLBI experiments in many places, including remote islands such as Minami-Torishima (Marcus Island) and Chichi-Jima (one of the Bonin Islands)[10]. Transportation of equipment such as data recorders and backends is therefore an important factors. Therefore light, small equipment has the advantage. The Mk-IIIa recorder is hard to move manually because of its weight and size. Also, it is difficult to maintain stable tape running if it is frequently transported.

Note also that (4) and (5) above give the K-4 an advantage for routine procedures.

6. Conclusions

The K-4 and K-3a (Mk-IIIa) data recorder systems were explained and compared. The K-3a (Mk-IIIa) has the advantage of compatibility with earlier standard VLBI recorders and the K-4 has the advantage of compactness and simplicity of use.

The K-4 data recorder is now used on a regular basis. VLBI experiments using K-3 and K-4 together are also successful.

As several institutions inside and outside Japan are interested in K-4, we would like it used more widely. Therefore we must make arrangements to process data from all over the world.

NRO (Nobeyama Radio Observatory, Japan) is developing a different type of K-4 data recorder which is dedicated for astronomy. K-4 now seems to be the standard in Japan in the fields of geodesy and astronomy.

I would like to thank the engineers of SONY company who developed the K-4 recorder, and Dr. N. Kawaguchi the former section chief who promoted the K-4 development project. I also thank Dr. A. E. E. Rogers of Haystack Observatory, who solved the problem of the Mk-IIIa head on our K-3 recorder.

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