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MEMO TO: M. Balister
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FROM: K. I. Kellermann

SUBJECT: K-3 System

The enclosed document describes the Japanese K-3 system mentioned in Rogers' VLBA Memo. Note that the so-called "super-wide" bandwidth mode is achieved by using two separate receivers covering the range 7.86 to 8.28 and 8.18 to 8.6 GHz. Unfortunately, there appears to be no discussion of the feed system.

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THE K-3 HARDWARE SYSTEM BEING DEVELOPED IN JAPAN AND ITS CAPABILITY

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ABSTRACT. The K-3 VLBI hardware has been developed since 1979 for the Japan-US joint VLBI experiments starting at the beginning of 1984. This paper presents a summary of the K-3 VLBI hardware which is composed of a 26 meter antenna, S/X receivers, a K-3 data acquisition terminal, wideband data recorders, a delay calibrator, a correlation processor, hydrogen maser oscillators and a water vapor radiometer. This paper also presents an error estimation on the joint experiments, and the result shows that we can expect the measurement with an accuracy of about 2 cm or better.

INTRODUCTION

The K-3 VLBI hardware has been developed since 1979 for the Japan-US joint VLBI experiments starting at the beginning of 1984.

The 26 meter antenna at Kashima Branch, the Radio Research Laboratories, will be used as one element of these experiments. An S-band receiver for a right-handed circularly polarized component and two X-band receivers for right- and left-handed ones will be assembled in the 26 meter antenna system by August 1983.

Development of two data acquisition terminals, each having an IF distributor, IF-to-video converters, a formatter, a decoder with a one-megabit memory, wideband data recorders and a delay calibrator, together with a correlation processor are proceeding on schedule and will be finished by March 1983. The data acquisition terminal is compatible with a Mark-III system and is also obedient to instructions of the same schedule program as one being used in the Mark-III field system.

Trial manufactures of a hydrogen maser oscillator, well-stabilized local oscillators, a water vapor radiometer and image rejection mixers have successfully been finished, and details of the K-3 hardware for operational use are designed.

We describe the results from pilot study and the design of the whole K-3 hardware, and also present a summary of the expected capability of the K-3 hardware system.

A 26 METER ANTENNA AND S/X RECEIVERS

A schematic sketch of a 26 meter antenna is shown in Figure 1. The antenna is a modified cassegrain antenna with a horn-reflector feed, and has an altitude-azimuth mount. The position of the intersection of axes, which is a reference point of a VLBI baseline, is shown in Table 1 in coordinate system of SAO-C7. The position will accurately be resurveyed by Geographical Survey Institute and precisely related to a Japanese datum origin (Kawaguchi,et al. 1982).

Tracking of celestial sources with this antenna is automatically performed by instructions from a computer within the accuracy of 0.01 degrees at maximum slew rate of 1 degree per second. Aperture efficiency of this antenna is expected to be 57 % at S-band and 45 % at X-band. Antenna noise temperature including noise due to feed system loss is to be 76 K at S-band and 90 K at X-band, at zenith angle of 45 degrees in a standard atmosphere.

The block diagram of the S/X feed and the waveguide circuit together with preamplifiers and frequency down-converters is shown in Figure 2. The S-band RHCP (Right-Handed Circularly Polarized signal) is guided to a S-band preamplifier through two directional couplers, the one is for injection of a delay calibration signal and the other is for adding some amount of noise to measure a system noise temperature. The noise adding and the system noise measuring are performed by device controllers in a data acquisition terminal. Both RHCP and LHCP (Left-handed one) signals in X-band are guided to two X-band preamplifiers through two waveguide switches and one ferrite switch, besides two directional couplers which have same functions as S-band. The SW1 (see Figure 2) alternates RHCP signal with LHCP signal.

The amplification of X-band and X'-band signals are performed by two independent preamplifiers as shown in Figure 2. Frequency allocation of both bands and response of a Band Pass Filter (BPF) in front of the X'-band preamplifier are shown in Figure 3. Usually, X-band and S-band RHCP signals are received in Japan-US joint VLBI experiments. At the same time, if LHCP signals in X'-band are received, the cross polarization of the incident waves can be measured at frequency range from 8180 MHz to 8280 MHz, a common band to X- and X'-band. The common band is also used for a test of system coherence. Both a noise and a delay calibration signal generated in a delay calibrator are received by X- and X'-band receivers, and are recorded on magnetic tapes, and are cross-correlated by a correlation processor in usual manner of VLBI. The result will show the degradation of coherence due to system instability or system imperfection. The X- and X'-band can be combined with each other by using a Ferrite SW, SW2 and BPF. As can be seen in Figure 3, the combination yields two times wider bandwidth for synthesis than that of a X-band only.

The S-band preamplifier is composed of field effect transistors (FETs), and the noise temperature is eatimated to be below 93 K throughout the whole receiving band from 2220 MHz to 2320 MHz. The X-band preamplifier is usually used in joint VLBI experiments and is a parametric amplifier followed by three FETs. Total gain will be above 50 dB and the noise temperature is expected to be below 70 K at frequency range from 8180 MHz to 8600 MHz. The X'-band preamplifier is composed of three FETs cooled electrically down to minus 60 C in physical temperature. The gain is above

40 dB and the noise temperature is below 100 K at frequency range from 7860 MHz to 8280 MHz.

Three down-converters are used to convert the frequencies of S-, X- and X'-band signals to IF frequencies, those are from 200 MHz to 300 MHz for S-band, from 100 MHz to 520 MHz for X-band and X'-band. The local oscillator signals are derived from a 10 MHz reference signal supplied by a hydrogen maser oscillator. The S-band local oscillator signal of 2020 MHz is phase-locked to the reference signal by a phase-locked oscillator (PLO). The output of the PLO, 2020 MHz, is multiplied by four to provide the X-band local oscillator signal of 8080 MHz. Another PLO supplies a local oscillator signal of 7760 MHz for the X'-band local oscillator and is also phase-locked to the same referece. Each converter has an image rejection filter and a line equalizer. The filter rejects undesired spurious or alleviates an interference from the lower sideband. The line equalizer compensates a rapid increase of attenuation at frequency above 100 MHz in IF cables.

K-3 DATA ACQUISITION TERMINAL

A K-3 data acquisition terminal is composed of an IF distributor, 14 video converters, a formatter, a decoder and a reference signal distributor.

The IF distributor has two channel units and a device controller. Each unit is independent and exchangeable each other and accepts an IF signal from 100 MHz to 520 MHz, disributes it to 8 LO IF channels (from 90 MHz to 230 MHz) and 8 HI IF channels (from 200 MHz to 520 MHz). The device controller controls the devices according to commands sent from a host CPU (HP-1000 model 10L) via a HP-IB interface, and also measures noise temperature of S-, X- and X'-band receiving system by turning a noise diode on and off in front of the receivers.

The 14 video converters accept 14 IF signals and output 28 video signals. The upper frequency of each video signal is selected out of 4, 2, 1, 0.5, 0.25 and 0.125 MHz. Each video converter has the same device controller as in the IF distributor and is also controlled by a host CPU. The local oscillator signal is supplied by a 10 KHz-step synthsizer phase-locked to the reference signal from a hydrogen maser oscillator.

The formatter has seven channel units and can accepts up to 28 video signals. Each unit samples 4 video signals into one bit and places them in a format prescribed so as to be compatible with a Mark-III format. A time code and all the timings for formatting are generated from a reference signal supplied by the hydrogen maser oscillator. The formatter is also controlled by a host CPU via a HP-IB interface.

The decoder performs the function of independently decoding two serial bit streams encoded and formatted by the formatter and of monitoring parity and synchronization errors. The results of decoding and monitoring are displayed on its pannel and are sent to a host CPU via a HP-IB interface. The decoder also has a one-megabit memory in it and stores a part of the same data as that which would have been written onto a tape. These data is utilized for the purpose of monitoring signal quality, detection of a delay calibration signal in the data, and of confirming real-time fringes if the data could be exchanged through an existing communication link.

The reference signal distributor supplies twenty 10 MHz signals to all the K-3 equipments and one 5 MHz signal to a delay calibrator as a reference. These signals are distributed or divided from one reference signal supplied by a hydrogen maser oscillator.

K-3 WIDEBAND DATA RECORDER

A K-3 wideband data recorder is composed of an instrumentation facility (a Honeywell M-96) for driving a tape and some self-developed electronics for recording and reproducing 28 channel-digital data sampled and formatted in a K-3 data acquisition terminal.

A digital head driver records the digital data of 4.5 Mbps on 28 tracks at a speed of 135 ips, and the resultant recording density is 33.3 Kbpi.

A read module and I/O modules for reproducing the 33.3 Kbpi data on 28 tracks at the maximum speed of 270 ips is under development and will be completed in December, 1982. The maximum reproducing speed of 270 ips is two times faster than the usual recording/reproducing speed. As noticed later, this means shortening of time required for data processing.

All the sequences of recording and reproducing are controlled by a controller. The controller has a micro processor to control the wideband data recorder according to instructions from a host CPU via a HP-IB interface and is always monitoring a footage counter for controlling the physical tape position.

K-3 DELAY CALIBRATOR

The S/X receivers at the antenna site and the data acquisition terminal in the ground building are connected by cables of about 62 meters. The variation of the cable delay is calibrated by a K-3 delay calibrator, the design of which is similar to a Mark-III delay calibrator.

The measured delay variation over 24 hours is shown in Figure 4. We can see a rapid decrease of the delay in the evening and an increase in the morning, and the peak-to-peak variation of about 0.1 ns was observed.

The resolution of the delay calibrator is about 0.5 picosecond and its instability is less than 5 picosecond.

K-3 CORRELATION PROCESSOR

Correlation processing is conducted by a HP-1000 model 45F computer with the aid of a HP-1000 model 10L computer and the use of a K-3 correlation processor. This correlation processing system is illustrated in Figure 5.

The correlation processor has 4 correlation units and 4 unit controllers. In each correlation unit, 8 pairs of data streams are cross-correlated and integrated. The correlated data are transferred to the 45F via a direct memory access line (DMA line) of HP-IB under controls of each unit controller. Necessary parameters for processing are transferred on the same line from the 45F to each unit controller. The unit controller sets these parameters to correlation units.

Synchronization errors between two data streams are calculated by the unit controller, and are reported to the 10L. According to the information, the 10L controls a speed of one wideband data recorder, while it keeps the other recorder at a constant speed.

At any time, an operator can monitor and query the processing status via a HP-IB interface of the 10L without disturbing the data transfer between the 45F and the unit controller via a DMA line.

The capability of the K-3 correlation processor are summarized in Table 3. The marked capability of this processor is the maximum integration period of about 8 second at the data rate of 4 Mbps and the maximum processing speed of 8 Mbps. The long integration capability may alleviate a load of the 45F and the fast processing speed may reduce the time required for the processing.

K-3 HYDROGEN MASER OSCILLATOR

We are now developing a new field operable hydrogen maser oscillator. Preliminary experiments on a small sized prototype maser oscillator have been done to obtain data for the design of a new operational maser.

The performance of the prototype maser is shown in Figure 6 and the short term stability of 7×10^{-15} has been obtained. In the figure, a dashed line shows a required performance and filled circles show measuring values on the prototype maser. We have already achieved a required performance. In the error estimation due to the frequency instability, however, we use the required performance as a worst case.

Making good use of this experience, a detailed design of the operational maser is determined as shown in Table 4 for a physics package and in Table 5 for electronics system. All works on two operational masers will be finished by March, 1983.

K-3 WATER VAPOR RADIOMETER

Tropospheric path delay due to water vapor along a ray path will be corrected by a K-3 water vapor radiometer.

The radiometer measures sky noise temperatures emitted by water vapor at two frequencies near the resonant frequency of 22.2 GHz. From these noise temperature measurement, tropospheric path delay is precisely determined as have already been made clear by Wu (Wu 1979). In the determination, however, there are some problems.

In the first, the measured noise temperature must not be interfered by other noise sources such as a noise from the ground or a noise generated by lossy circuits in the radiometer. We can correct the unkown bias adding to the true sky noise temperature by a tipping method or using a liquid nitrogen cooled dummy in front of the antenna. For making the tipping method effective, we need to measure the sky noise temperature down to the elevation angle of less than 10 degree (equivalent to the air mass number of larger than 5) as can be seen from Figure 7. The figure, the result of covariance analysis on the tipping curve, shows the estimation error of the unknown bias (σ_{T1}) caused by the observation error of 0.5 K, when the tipping is conducted down to the elevation angle shown on the abscissa. We design our radiometer so as to measure the sky noise temperature down to the elevation angle of 10 degree without interference from the ground, by using a narrow beam, low sidelobe antenna.

In the second, coefficients used in the estimation of path delay from the sky noise temperature depends on meteorlogical condition. To avoid this dependency, we choose optimum pairs of frequency of 20.0/26.5 GHz or 20.3/31.4 GHz as is recommended by Wu (Wu 1979), and will confirm the validity of the coefficients by launching radiosondes.

The radiometer of a temperature-stabilized Dicke-type are designed and will be finished in May 1983. The error of the sky noise measuring are expected to be less than 1 K.

CONCLUSION

We present a summary of a K-3 hardware system being developed in Japan. In conclusion, we will summarize the error caused by the K-3 hardware system in Table 6. In the estimation, we suppose a baseline between the OVRO 40 m antenna and the Kashima 26 m antenna. From this table, the total observation error of about 2 cm will be expected.

We heartily hope that the Japan-US joint experiments will successfully start and the data will give new information to the fields of geodesy and crustal plate mortion.

ACKNOWLEDGMENT

We would like to thank to Dr. A.E.E.Rogers for his kind helps in designing K-3 data acquisition terminal, Dr. H.Hinteregger in designing wideband data recorder, Dr. G.M.Resch in designing a water vapor radiometer, Dr. A.R.Whitney in designing a correlation processor, and many other VLBI researchers for their kind suggestions and encouragements.

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Wu,S.C.,1979: Optimum Frequencies of a Passive Microwave Radiometer for Tropospheric Path-Length Correction, IEEE transaction, vol.AP-27, NO.2.

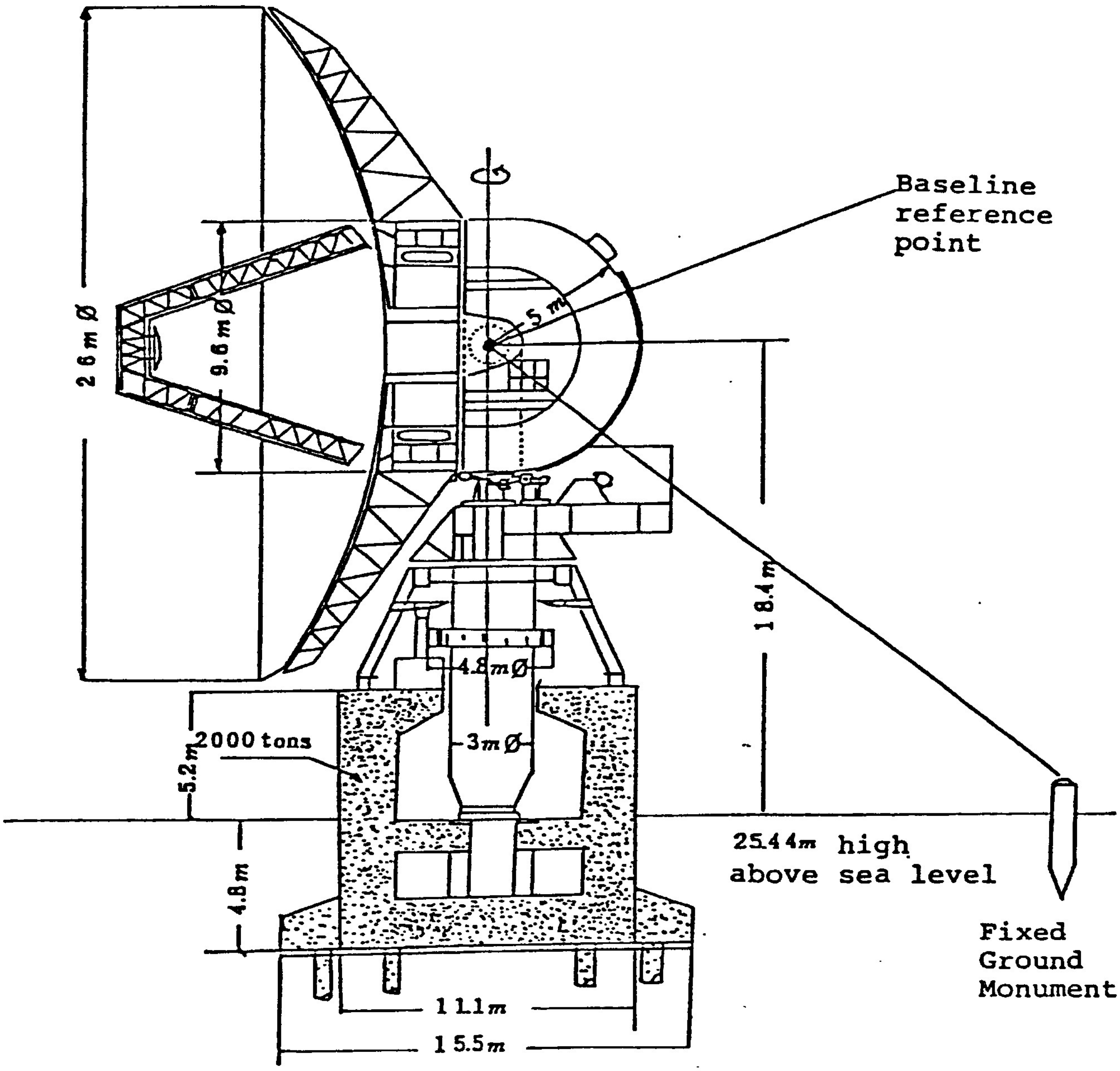

Figure 1. The schematic sketch of the 26 meter antenna at Kashima

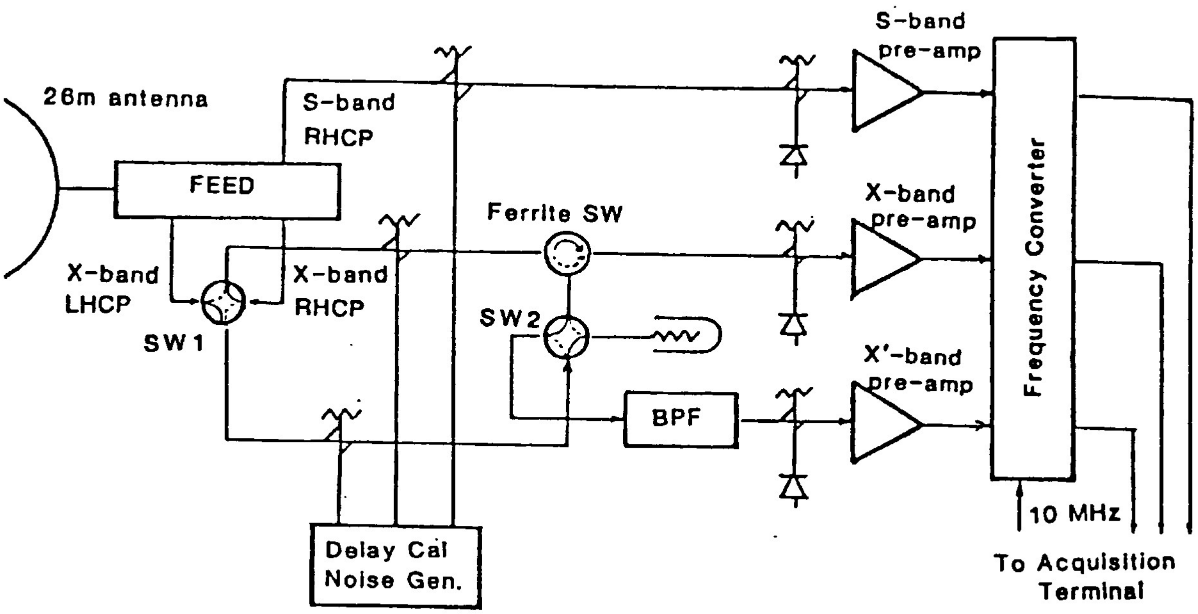

Figure 2. The block diagram of the feed and the S/X receivers

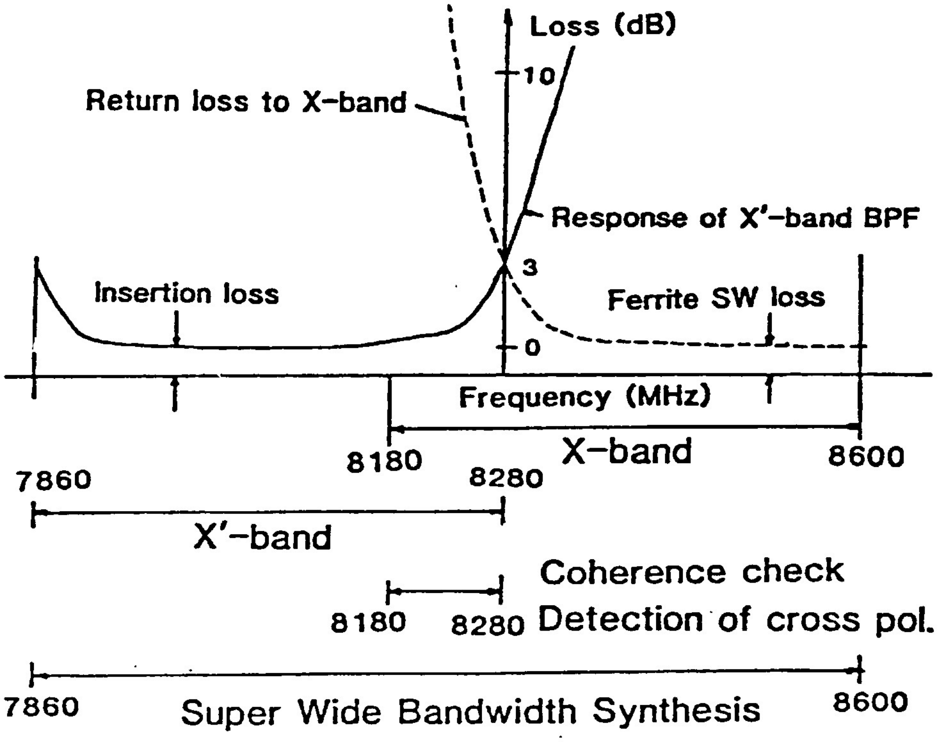

Figure 3. The frequency allocation of X- and X'-band

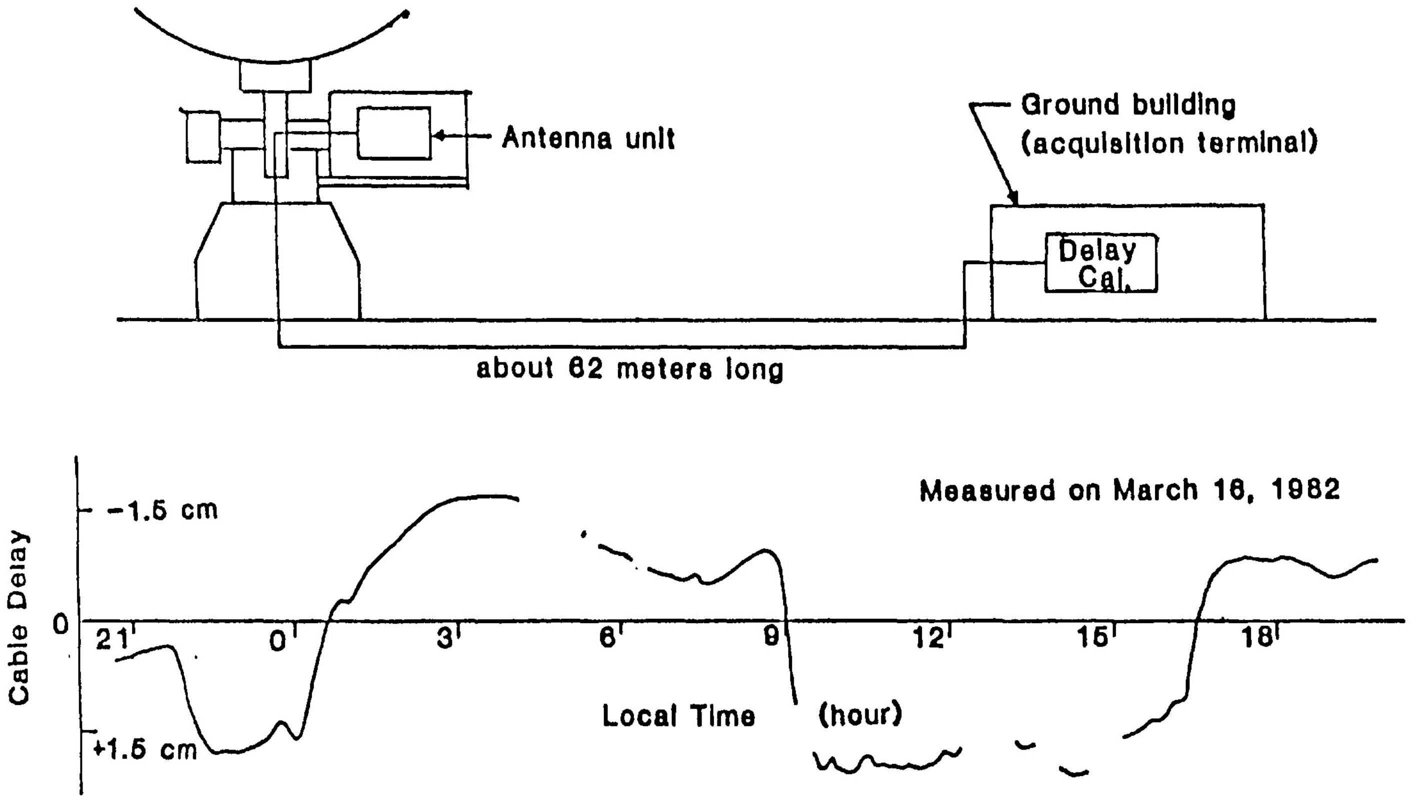

Figure 4. The measured cable delay variation over 24 hours

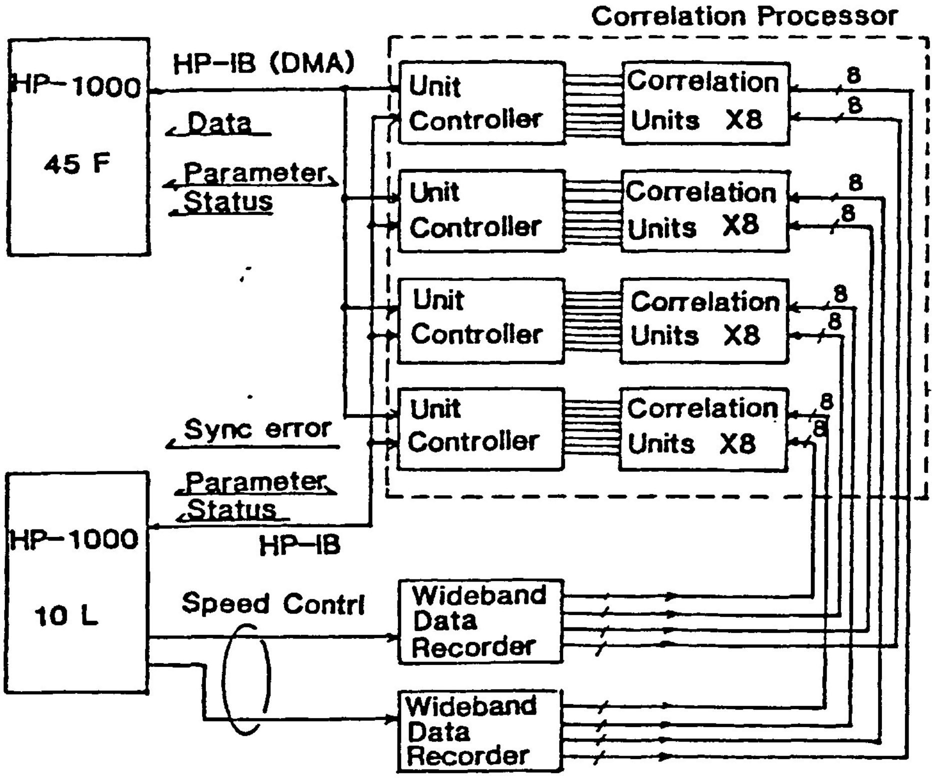

Figure 5. The correlation processing system

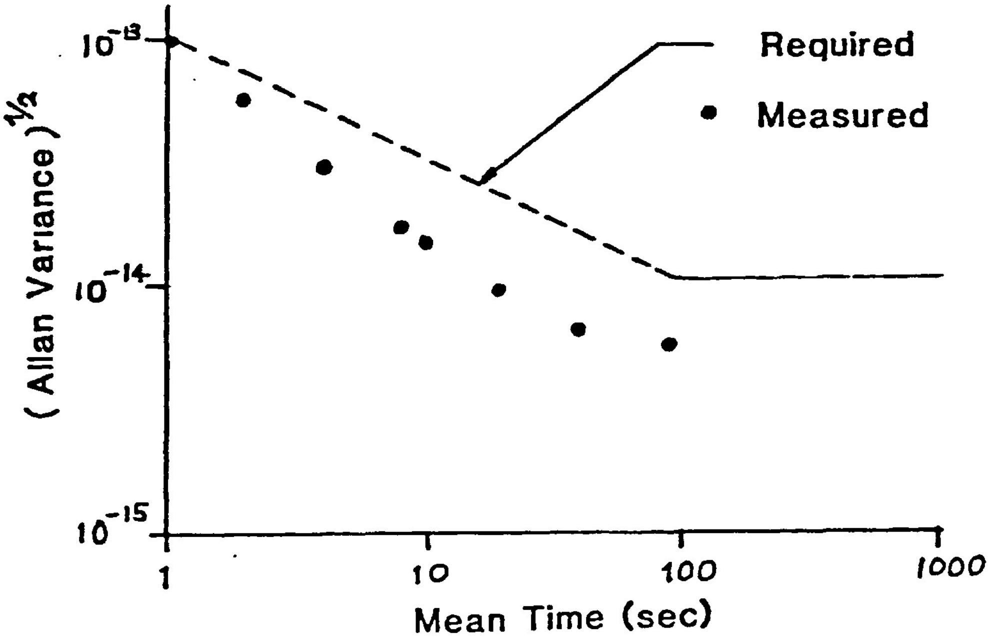

Figure 6. The performance of the prototype hydrogen maser oscillator

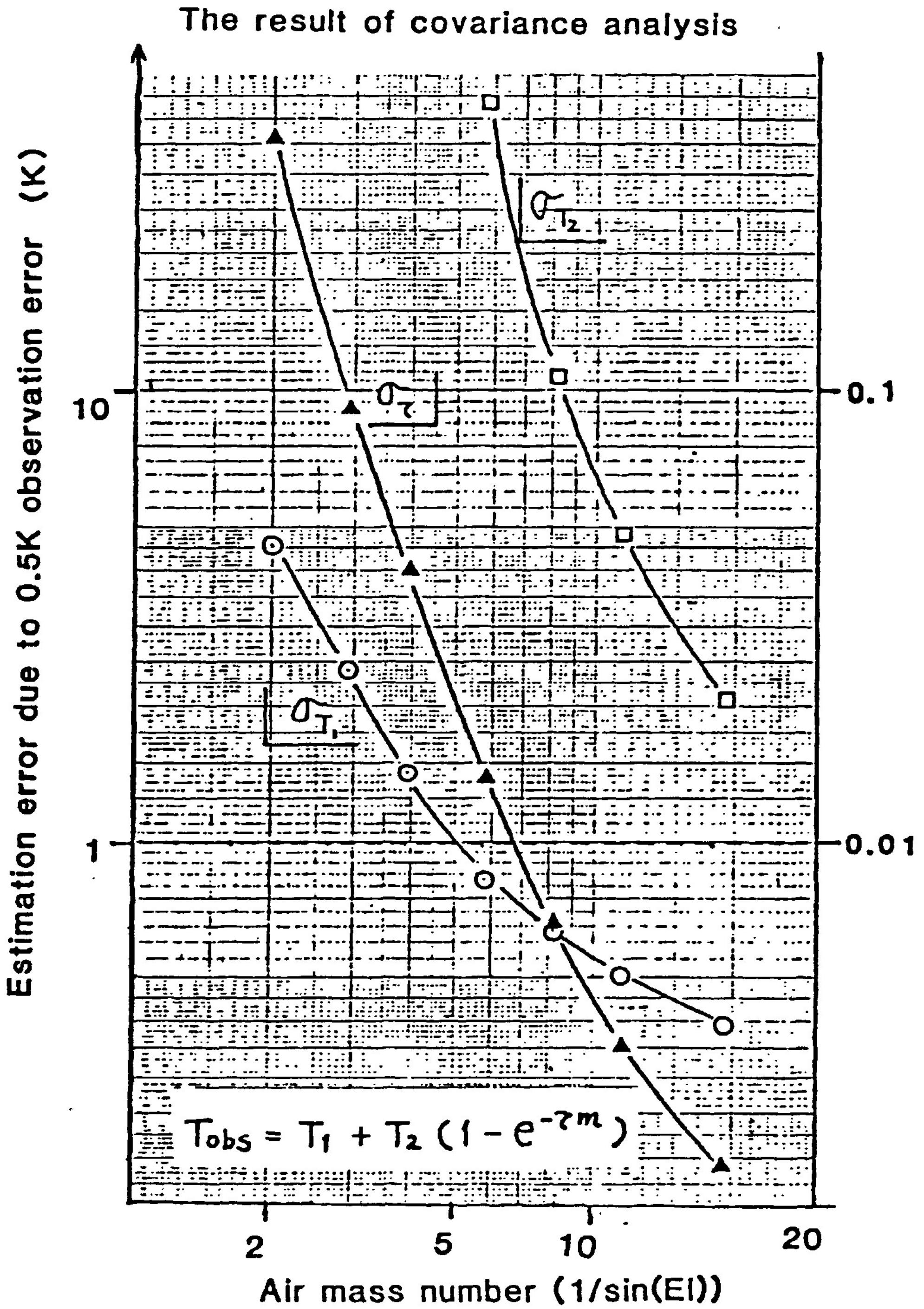

Figure 7. The result of covariance analysis on the tipping equation

Table 1. The position of the 26 meter antenna in SAO-C7 coordinate system

Latitude	:	140°39'45."6
Longitude	:	35°57'15".1
Geoid height	:	77.08 meter

Table 2. Summary of electrical characteristics of the 26 meter antenna and the S/X receivers

frequency / item	S-band	X-band
Frequency Range	2200-2320 MHz	8180-8600 MHz
Antenna Diameter	26 meter	26 meter
Aperture Efficiency	57 %	45%
Antenna Gain	52.8 dB	63.2 dB
Antenna Noise Temperature	70 K	60 K
Waveguide Circuit Loss	6 K	30 K
Preamplifier Noise	93 K	70 K
Total G/T	30.5 dBK	41.2 dBK

Table 3. The performance of the K-3 correlation processor

Number of Channels	32
Maximum Processing Speed	8 Mbps
Programmable Delay	enable up to 128 bits
Correlation Lags	complex 8 bit-lags
Integration Period	5 msec to 8.38 sec at 4 Mbps of data rate
Buffer Memory	20 Kbits
Fringe Rotation	
Phase Resolution	0.02 micro-radian
Phase Rate Resolution	0.93 mHz (Phase Acceleration Enable)
Rotation Pattern	3-level
Fractional Bit Correction	90 deg. phase jump

Table 4. The design of the operational hydrogen maser oscillator for the physics package

Magnetic shield	1.5 mm Permalloy, 4 shields
Magnetic shielding factor	15,000
Resonant cavity	27.5 cm dia. and 30.4 cm long Q_0= 50,000
Storage bulb	18.0 cm dia. quartz
Temperature	cavity @ 49 ± 0.001 °C
State selector	hexapole magnet 7 kGauss
Collimator	multi channel collimator each channel 25 µm dia. and 0.5 mm long
Source gas pressure	0.1 Torr
Source bulb	3 cm dia. and 5 cm long pylex
Dimension	90 cm wide, 80 cm deep and 165 cm high
Weight	ca. 700 kg

Table 5. The design of the operational hydrogen maser for the electronics system

Power supply	AC 200V and AC 100V
Receiver	
Preamp.	2.2 dB N.F. commercial unit
1st mixer	Double balanced image rejection mixer commercial unit
L.O. Multiplier	phase locked multiplier commercial unit
Synthesizer	$7\text{x}10^{-13}$ resolution, commercial unit
VCXO	HP10811B
10 MHz buffers	120 dB isolation
Gas pressure controller	custom made at RRL
$P_d H_2$ purifier	custom made at RRL
C-field	0 to 20 mGauss, regulated $1\text{x}10^{-5}$
Signal outputs	10 MHz, +13 dBm, 50 ohm; 7 channels 1 pulse per second TTL level; 2 channels Monitor signal

Table 6. The observation error estimation of the VLBI experiment between OVRO 40m and Kashima 26m

Error sourc	error	comment
Antenna and Receiving System	54 psec	1 Jy, 300 sec, Mode E
Hydrogen Maser Oscillator	18 psec	clock instability
Delay Calibrator	5 psec	time interval counter error of 1 micro-sec at 25 Hz
Wet Component Path Delay	38 psec	radiometer error of 1 K
Dry Component Path Delay	11 psec	pressure gauge error of 0.1 mbar
Phase Scintillation	6 psec	integration time of 300 sec
Total RSS	70 psec	about 2 cm