3. Antenna System Improvements

3.1 34-m Antenna System Improvement

By

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ABSTRACT

The Kashima 34-m antenna was manufactured by TIW Systems (now VertexRSI) in the United States and constructed in 1987 as the main station of the Western Pacific VLBI Network. For more than thirteen years, the radio telescope has been used for both geodetic VLBI and radio astronomy. Its control system is continuously being improved to provide better performance. This paper reports on past improvements and technical enhancements to the 34-m antenna system with a focus on hardware.

Keywords: Radio telescope, VLBI, Radio astronomy, Low noise receiver, Optical fiber

1. Introduction

The 34-m antenna at the Kashima Space Research Center of the Communications Research Laboratory (CRL) was constructed in 1987 as the main station of the Western Pacific VLBI Network[1]. As shown in Fig. 1, it is a large parabolic antenna using an AZ-EL drive system. The antenna was manufactured by TIW Systems in the United States (now VertexRSI) and delivered to CRL specifications based mainly on antennas developed for stations of the Deep Space Network (DSN) operated by the National Aeronautics and Space Administration (NASA). Since then, CRL has made various improvements to the antenna and has raised its accuracy. This article surveys the functional improvements made to the antenna over a period of more than 13 years since its construction. Our objective here is to provide future users with information deemed necessary for achieving an understanding of the 34-m antenna system.

Fig. 1 The Kashima 34-m antenna

2. Basic System

Main specifications of the 34-m antenna are listed in Table 1 and its control system is overviewed in Fig. 2. The initial performance of the antenna was described in detail at the time of its construction in a special issue of the Review of the Communications Research Laboratory[1]. A key change since then is the antenna's maximum drive speed. Receiver performance is summarized in Table 2.

2.1 Overview of drive system

The block diagram in Fig. 2 shows how angle-data signals for the 34-m antenna are sent from the Observation Control PC to the Antenna Control Unit (ACU) via the Antenna Control PC. The ACU compares the actual angles with the command angles and drives four azimuth (AZ) motors and two elevation (EL) motors to perform tracking. As shown in Table 1, wire-wrap is large compared to ordinary antennas, which makes for flexible tracking when switching between astronomical objects. In addition to the ACU, the antenna can be operated by a Portable Control Unit (PCU) at close range for maintenance purposes.

Signals from limit switches on the AZ and EL motors and elsewhere and from emergency-stop switches placed at various locations are input to a logic board inside the Antenna Drive Cabinet (ADC). If, on the basis of these signals, an abnormal situation arises, the antenna is immediately stopped. The emergency-stop switches can also be used to prevent erroneous movement of the antenna when conducting maintenance inside or near movable sections.

2.2 Overview of receiver control system

A key feature of the 34-m antenna is its ability to receive signals in various frequency bands and to switch between these bands in a relatively easy manner. Past multi-frequency receive antennas required a certain amount of time and labor to switch the receiver, but this antenna can be controlled remotely without on-site human intervention. What makes this possible is receiver

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Table 1 Main specifications of 34-m antenna

Main reflector aperture	34.073m
Latitude	North latitude 35°57′ 05.76″
Longitude	East longitude 140°39′ 36.16″
Height of antenna center above sea level	43.6m
Height of antenna position above sea level	26.3m
Antenna shape	Modified Cassegrain reflector
Mount shape	AZ-EL mount (4 AZ motors, 2 EL motors)
Panel surface accuracy	0.17 mm r.m.s. (EL=45°; at time of construction)
Drive range azimuth direction	North ±270° (during automatic operation)
azimuth direction	North ±359° (all other times)
elevation direction	6.8°—90.2°
Subreflector	Diameter 3.8 m
5-axes drive-control range	Each axis: ±60mm
Wind resistance	Maximum instantaneous wind speed: 60 m/s
Weight	About 370 tons
	AZ	EL
Maximum drive speed	0.8°/s	0.64°/s
Maximum drive acceleration	0.4°/s²	0.36°/s²
	(Values measured during periodic maintenance in FY 2000)

Table 2 Receiver noise temperature T_{LNA} and system noise temperature T_{SYS}

BAND	Frequency (GHz)	T_{LNA} (K)	T_{SYS} (K)
L	1.35—1.75	18	45
S	2.15—2.35	19	72
C	4.60—5.10	25	108
X-n	8.18—8.60＊	41	52
X-wH	8.18—8.60＃	41	65
X-wL	7.86—8.36＃	40	61
Ku-L	14.40—14.90	60	130
Ku-H	14.90—15.40	64	110
K	21.80—23.80	300	330

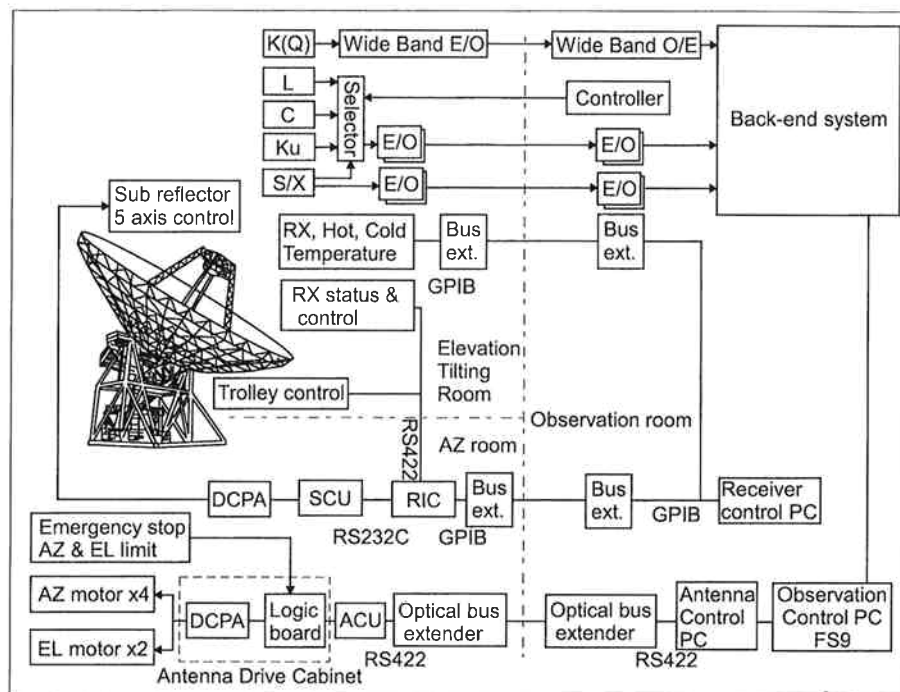＊8GHz LNA normal-band use   ＃8GHz LNA broadband use

Fig. 2 Outline of the 34-m antenna control system

switching by trolleys that move up and down along linear rails and a sub-reflector 5-axes control mechanism that moves the position of the Cassegrain focus to one of several feeds.

As shown in Fig. 2, the trolleys can be controlled remotely from the Receiver Control PC in the Observation Room via the Rx-band Interchange Computer (RIC). Receiver control (power ON/OFF, left-circular/right-circular polarization switching, etc.) and receiver-status monitoring can also be performed. Raising and lowering of the trolley is carried out while the antenna is pointing toward the zenith.

The Sub-reflector Control Unit (SCU) in the AZ Room controls the sub-reflector's position along five axes. Values for the X, Y, Z1, Z2, and Z3 axes are input from the SCU control panel and the sub-reflector is moved to the specified position through a servo loop. Sub-reflector position can be monitored by the Receiver Control PC in the Observation Room.

3. Antenna Improvements

3.1 Overview of receive system

The optical system of the 34-m antenna is a Cassegrain feed in which one of several receivers can be positioned at the Cassegrain focus by a trolley. In addition, the focus at the trolley, which has multiple feeds, can be varied by a sub-reflector 5-axes control mechanism.

The antenna mounts cooled, low-noise receivers commonly used in VLBI and radio astronomy. To achieve low noise, the first-stage low noise amplifier (LNA) is cooled to about 20K through a refrigerator using helium gas, and to calibrate receive power, a cold load at about 50K and a hot load at normal temperature are provided. In C-band, however, a cold load is not provided since the original receiver was upgraded to a compact, maintenance-free, and easy-to-install cooled receiver. These calibration signals are input to the receiver in place of receive signals by the waveguide switcher. Switching between left-circular and right-circular polarization can be performed by remote control through the waveguide switcher.

3.2 Changes to the L-band receiver

To improve accuracy in pulsar timing observations, the L-band receiver was upgraded to broadband in July 1993 from the original receiver system shown in Fig. 3(a) to the 1.6-2.4 GHz system shown in Fig. 3(b). In March 1995, however, the 1.38-1.45 GHz receive band of a Russian 64-m antenna scheduled for a pulsar VLBI experiment with the 34-m antenna required that local oscillators and such be returned to original specifications (local oscillator frequency: 1.25 GHz), as shown in Fig. 3(c).

In recent years, moreover, there has been an increase in interference as the L-band has come to be used for mobile communications by portable telephones and other devices. For this reason, narrow-band-pass filters have been placed between the first- and second-stage LNAs so that the post-amplifier of the second stage does not saturate. Depending on antenna direction, however, the first-stage LNA may still saturate because of interfering waves. In this case, appropriate countermeasures should be taken such as inserting a cooled band-pass filter before the first-stage LNA to prevent thermal noise from increasing.
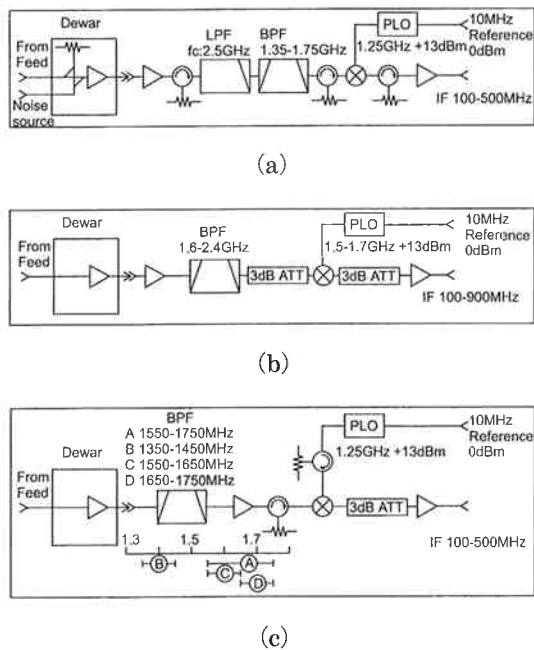
(a)

(b)

(c)

Fig. 3 a) Original L-band receiver system; b) L-band receiver system after broadband upgrade; c) Current L-band receiver system after returning to original specifications and incorporating interference countermeasures

3.3 Change to the S/X band receiver

The S/X band (2/8 GHz) has been the main receiving band for geodetic observations using the 34-m antenna. The S/X band receiver, moreover, was manufactured so that two frequencies could be received simultaneously by the same feed in geodetic VLBI experiments. The first-stage LNA was replaced in 1998 due to a rise in receiver noise temperature.

3.4 Changes to the K-band receiver and implementation of a 5-7 GHz IF system

To enable broadband observations to be performed, the 22-GHz system was changed to the broadband optical-fiber transmission system shown in Fig. 4 in addition to converting the intermediate-frequency (IF) system to optical fiber as described later. The frequency conversion section was improved in accordance with this. The system first converts 21.8-23.8 GHz signals to 5-7 GHz IF signals for transmission over optical fiber. An ORTEL 3514A-020 having a frequency band of 0.1-10 GHz are used for the optical transmitter. Next, with these 5-7 GHz IF signals as input, the system is designed so that conventional IF signals or 500-1000 MHz IF signals can be supplied by selecting a 4.5- or 5-GHz local frequency. The first-stage LNA was also replaced in 1996 due to a rise in receiver noise temperature.

3.5 Replacement of the C-band receiver

We have been using a Cooled Low Noise Amplifier (CLNA) manufactured by MITEQ in the United States for the 5-GHz receiver since September 1999. This CLNA
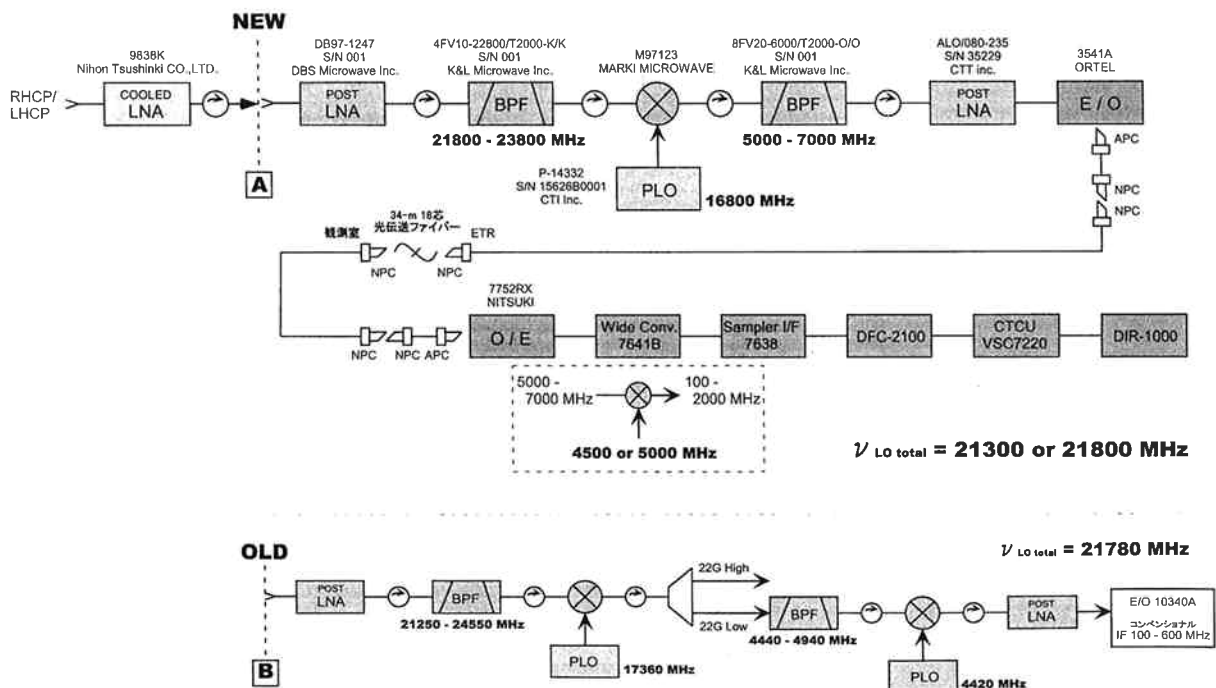

Fig. 4 22-GHz receiver system and 5-7 GHz IF signal-transmission system

Table 3 Performance of normal-temperature LNA and CLNA

	T_{LNA} (K)	T_{SYS} (K)	$T_{SYS} - T_{LNA}$ (K)
Normal-temperature LNA (Nihon Tsushinki) 1999/12/08	92	127	35
CLNA (MITEQ) 2000/04/12	25	108	83

features closed-cycle cryogenics using a compressor employing refrigerant that requires no vacuum to be drawn. This makes for a maintenance-free process and enables cooled High Electron Mobility Transistors (HEMT) to be used.

The 34-m antenna had been using a room-temperature LNA for VLBI experiments, but the demand for a system with even lower noise meant that performance had to be improved. In this regard, cooled HEMTs that came to be used for conventional radio-astronomy observations in the microwave band required a helium compressor, a helium supply system, Dewar equipment and other large facilities. The above CLNA, however, can achieve a cooled receiver in a much easier manner. Its compact configuration, though, means no cold load, with the result that calibration of receive power using a cold load cannot be performed.

One CLNA unit (309.4 mm × 189.7 mm × 258.6 mm) combines a high-performance LNA and cooling system that can achieve a performance of about 25K in receiver noise temperature by simply connecting a DC24V power supply. This level of performance is equivalent to that of conventional cooled HEMTs. Figure 5 shows the CLNA mounted on the antenna and Table 3 summarizes performance before and after LNA replacement. We point out here that the CLNA must be kept in a horizontal state if the cooling section is to demonstrate stable performance. For this reason, we constructed a holder with a swivel bracket to mount the CLNA onto the antenna. This keeps the CLNA horizontal regardless of the elevation angle. On the other hand, the signal from the waveguide is input to the CLNA through a 1-m long cable, and the resulting cable loss prevents the CLNA from demonstrating full performance and makes for a larger T_{SYS}-T_{LNA} value in Table 3. As a result, the CLNA turned out to be only slightly better in terms of system noise temperature. To resolve this problem, we plan to introduce a new system in April 2001 that separates only the amplifier section of the CLNA and cools it by feeding refrigerant by an umbilical cord. This scheme will eliminate the current cable-loss section and make it possible to achieve a system noise temperature of about 70K.

3.6 Development of a millimeter-wave 43-GHz receiver

Development of a Superconductor Insulator Superconductor (SIS) type of receiver to receive 43-GHz masers emitted from silicon monoxide (SiO) was undertaken from 1995 to 1998. When mounting such a receiver on the 34-m antenna, the biggest problem is how to achieve
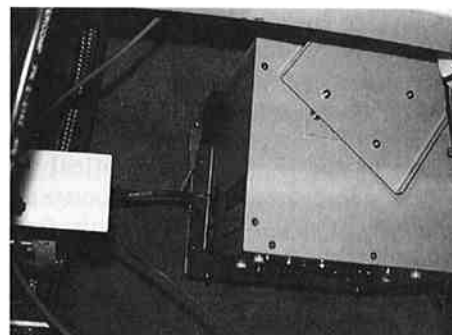

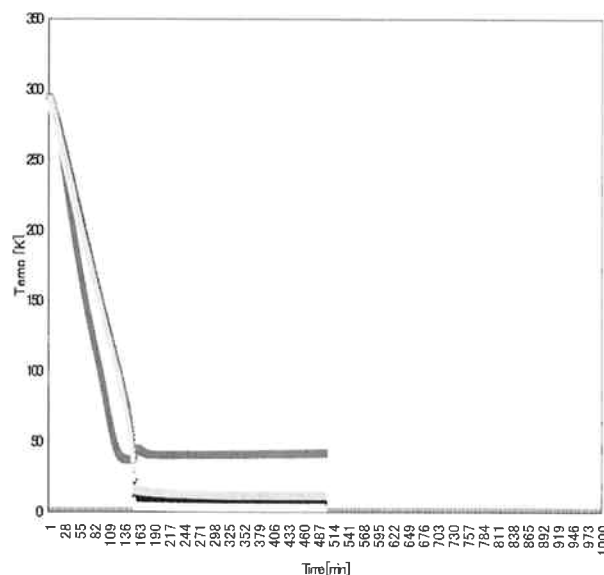Fig. 5 CLNA mounted on antenna

Fig. 6 Cooling data for GM refrigerator. Cooling to the cooling stage of 4K and the intermediate stage of 50K takes about two hours, which is exceptionally fast compared to existing JT refrigerators.

device cooling by a refrigerator. In particular, the superconducting nature of the SIS device requires that cooling be performed to about 4K at which the superconducting effect in question appears. At that time, however, we found that the performance of a compact Gifford McMahon (GM) refrigerator was not sufficient, and we therefore developed a system that installs a

refrigerator in a vacuum dewar at an angle of 45°. As shown in Fig. 6, this refrigerator can achieve desired cooling in an extremely short period of time of about two hours. In the first observation conducted with this receiver, we succeeded in detecting SiO radiation in the vicinity of VY_Cma (VY star in Canes Venatici). Receiver noise is also favorable as shown in Fig. 7. The receiver is installed in the 34-m antenna as shown in Fig. 8. Here, however, there is a rise in antenna temperature due to the radome. It requires sub-reflector adjustments in addition to bias adjustments in the SIS receiver. As a consequence, the control system is more complex than that of a HEMT receiver and preparations are now under way to upgrade to another HEMT system. Research in these areas is being conducted jointly with the National Astronomical Observatory (NAO) and Ibaraki University.

3.7 Conversion of the IF system to optical fiber

The system adopted at the time of antenna construction transmitted 100-600 MHz IF signals from the Receiver Room to the Observation Room over a low-loss coaxial cable. In this system, an equalizer amplifier was used to compensate for increase in transmission loss at high frequencies, which is a characteristic of coaxial cable. However, with the aim of preventing change in phase characteristics due to change in temperature, we upgraded to an optical-fiber transmission system.

Figure 9 shows the optical transmitter and IF-signal switcher and Fig. 10 shows the optical receiver and IF signal-switching controller. An ORTEL 10340A having a frequency band of 0.1-5.0 GHz are used for the optical transmitter, an ORTEL 10450A having a frequency band of 0.01-3.0 GHz for the optical receiver, and a frequency band of 0.01-2.0 GHz for the output amplifier. The IF-output frequencies are 100-600 MHz, the same as those of conventional systems.

Being a multi-frequency receiver, the 34-m antenna features ten systems of IF signals from the various receivers. Table 4 shows how an IF-transmission system consisting of four optical cables in total has been set up on the basis of receiver usage frequency. In this system, two lines are used exclusively for X-band and S-band connections while the other two lines are used for all other signals in conjunction with the IF switcher. With regard to the latter two lines, the IF signal-switching controller in the Observation Room can be used to re-
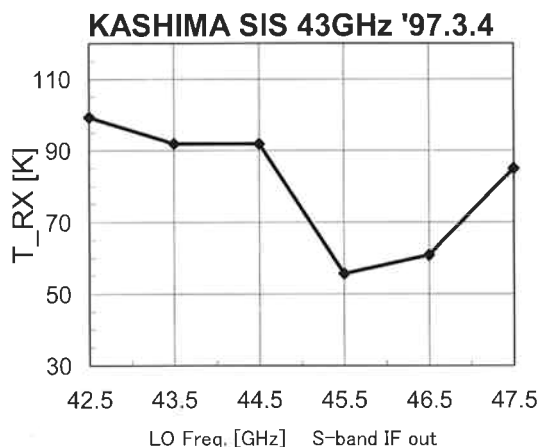

Fig. 7 Noise temperature of completed SIS receiver

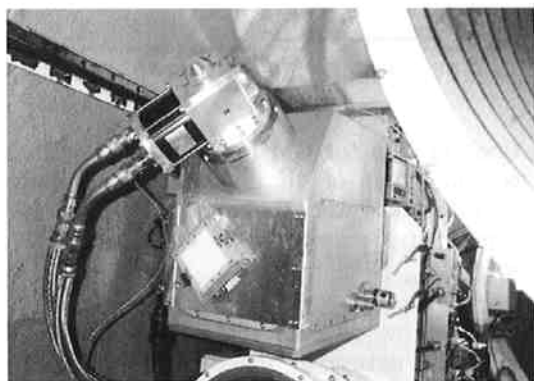**Fig. 9 Optical transmitter and IF-signal switcher in the Receiver Room**

Fig. 8 View of upper side (in direction of injected radio waves) of 43-GHz receiver connected to 34-m antenna feed; a polarization panel is installed in the diamond-shaped section.
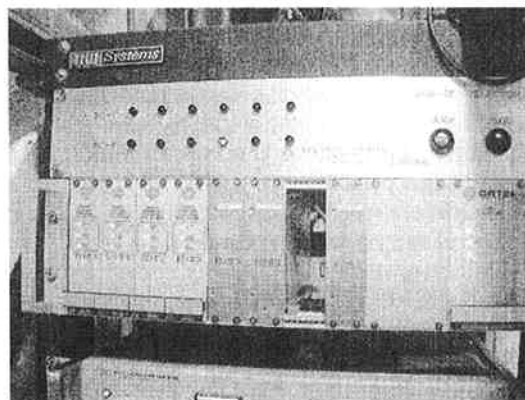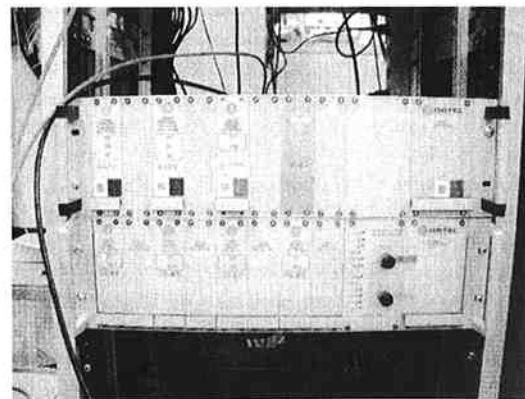

Fig. 10 Optical receiver and IF signal-switching controller in the Observation Room

Table 4 Optical fiber system and receiver IF signals

Line 1	X-WL, 15G-L, 10G, 22G-L, AUX
Line 2	X-WH, 1.5G, 15G-H, 22G-H, AUX
Line 3	X-band (normal band width) exclusive
Line 4	S-band exclusive

motely select signals other than S/X band signals for transmission by optical fiber to the Observation Room. Although omitted in Fig. 2, an amplifier with a gain of 38 dB has been installed before the input to the electrical/optical (E/O) converter to compensate for the large loss in the converter.

Although the coaxial-based IF transmission system has been converted to an optical-fiber transmission system as described above, the transmission band is still the conventional one of 100-600 MHz. Considering, however, that the Key Stone Project (KSP)[2] and other VLBI systems are migrating to the 500-1000 MHz octave band, an up-converter for converting 100-600 MHz to 500-1000 MHz is being installed in the Observation Room.

3.8 Operating software

The New Kashima Automatic Operating System (NKAOS) was developed to perform VLBI observations using the Kashima 34-m antenna[3]. This operating system is based on the Kashima Automatic Operating System (KAOS) used by the Kashima 26-m antenna.

To perform a VLBI observation, an observation schedule called an "original schedule" is created. This schedule includes all information pertaining to observation stations and is even used in correlation processing. An observation station, however, cannot use the original schedule in its created form. For this reason, an observation station employs a field system (VLBI automatic observation software and control computer) that extracts from the original schedule only the information needed by the observation station and creates and executes an observation schedule using an automatic-control language. This schedule, called a "SNAP schedule" (where SNAP stands for Standard Notation for Astronomy Procedures), consists of work instructions in a time sequence.

In this regard, KAOS, which was created on the basis of field systems developed by the National Aeronautics and Space Administration Goddard Space Flight Center (NASA/GSFC) in the United States, has been performing automatic VLBI observations by SNAP schedules. A SNAP schedule, however, describes one action per line, which means a huge number of lines in the case of a 24-hour observation, for example. As a consequence, in operations involving interruptions and restarts, a fair amount of time may be needed to read up to a break point in the schedule. Contrary to this, CRL has created a VLBI observation software that uses the original schedule. This software is used for ultra-compact 3-m mobile VLBI stations and is called the Mobile Automatic Operating System (MAOS). Actual operating results have already been obtained and it has been found that use of the original schedule simplifies observation work.

In light of the above, we not only use the original schedule in NKAOS but also employ a system in which SNAP commands are defined separately and called up during an observation. This enables complex control tasks like controlling the frequency of a video converter to be performed. The computer used by NKAOS is a Hewlett-Packard HP1000/A400. This machine is the successor to the HP1000 computer used by KAOS and can use device-control subroutines (written in assembler or Fortran languages) developed under KAOS without modification. As a result, NKAOS could be developed in a relatively short time by creating a main program (in Fortran) that reads the original schedule and generates SNAP commands from the schedule.

The specific operating system here has a function called "RTE-A" for controlling devices in real time and abundant subroutines supporting this function. The system is also capable of multitasking—it can run several device-control programs simultaneously and manage them in a uniform manner by enabling programs to share parameters in a common system area. For example, multiple devices including the data recorder can be simultaneously controlled while performing antenna tracking. We mention here that this operating system was developed in parallel with the construction of the 34-m antenna, and tracking of astronomical objects, control of the data recorder, etc., were checked using the 26-m antenna. A prototype of the system was nearly ready by the time the 34-m antenna was completed.

Initially, the procedure was to read and store an original schedule in memory and then execute it. However, with improvements in VLBI observation methods, formation of sub-networks, etc., the format of original schedules underwent many changes. A need was therefore felt for the capability of verifying whether a schedule would be correctly read. In order to enable this checking to be performed beforehand, NKAOS was revised to generate a specific-format schedule file called "NKAOS.SKD". This intermediate file can be easily edited and can be used, for example, to make automatic observations of interplanetary scintillation, pulsars, etc.

The NKAOS is capable of controlling both K-3 and K-4 types of data recorders. The K-4 type of data recorder, however, uses cassettes, and making use of this feature, an automatic cassette changer DMS-24 was introduced in 1994 enabling long-term unmanned observations possible. Using 24 cassettes of tape, and given that 200 minutes of recording can be performed per cassette when observing at 64 Mbps, 80 hours of continuous recording became possible. Furthermore, considering that

about half of the time in an ordinary geodetic VLBI ob-
servation is spent switching between astronomical objects,
the total recording period could actually be doubled to
160 hours. In other words, about one week of unmanned
observations could be performed, a world's first at that
time. The development concept for NKAOS originated in
the automatic control system of the Key Stone Project
(KSP) for observing crustal deformation in the Tokyo
metropolitan area, which began development in 1993.

As described above, original software for radio tele-
scopes called NKAOS was developed and deployed at the
Kashima Space Research Center (KSRC). On the other
hand, common operating software that could be used by
all observation stations would be a great advantage in
terms of creating and adjusting observation schedules.
With this in mind, we are now working with
NASA/GSFC on extending Field System 9 (FS9), a world
standard in VLBI operating software, for use by the 34-
m radio telescope.

There are two main features of FS9: first, it has
been designed to run on Linux, a free operating system
with a solid reputation, and second, it can be distributed
in the form of common source code. The second feature
in particular makes it easy for any observation station to
investigate the cause of a problem that has occurred and
to feed back solutions to other users.

The specifications of the personal computer used for
FS9 at KSRC are listed in Table 5. In this way, a system
can be constructed using hardware and software com-
monly used in personal computing and the entire system
can be constructed at a relatively low price. At KSRC,
the following work on extending FS9 has been performed
in cooperation with the Geographical Survey Institute
(GSI), and NASA /GSFC.

First, work was performed to enable the K-4 recorder
that is widely used in Japan to be used with FS9. Origi-
nally, FS9 supported standard recorders in the United
States like the Mark-III and VLBA, and was later ex-
tended to support the Mark-IV, an enhanced version of
the Mark-III, and the S2 recorder developed in Canada.
With support of K-4 completed, support of all standard
data recorders used in the world is now provided with

the exception of especially advanced recorders. At pre-
sent, functions related to K-4 are provided in an auxil-
iary distribution for expansion to K-4 and are not part
of mainstream FS9. In the future, however, K-4 functions
will be fully incorporated in the mainstream FS9 distri-
bution.

Next, work was performed to give a display function
to the routine (fivpt) that determines antenna offset val-
ues from observations. The FS9 field system is distrib-
uted with a software package for calibrating antenna
axes, and this software makes it extremely easy to com-
pute final antenna offset parameters. However, the main
routine of this package called "fivpt" returns only nu-
merical data, which is not conducive to obtaining an in-
tuitive understanding of the situation in individual offset
observations. To resolve this problem, we created a sub-
routine that makes it easy to visualize returned numeri-
cal data (baseline offset, slope inclination, and para-
meters fitted to a Gauss distribution). An example of
plots generated by this subroutine is shown in Fig. 11.
The horizontal axis corresponds to the offset value (de-
grees) while the vertical axis corresponds to observed
temperature. The upper graph shows results in the lati-
tude direction and the lower graph those in the longitude
direction. Each observation was performed at angular in-
tervals equal to 0.4 of the beam width in both the lati-
tude and longitude directions. This figure therefore
shows that the effects of offset during observations can
be extremely small (under 1/10 the beam width) because
appropriate offset parameters for the 34-m antenna are
given. This subroutine is scheduled to be incorporated in
the upcoming K-4 version of FS9.

A routine for monitoring wind speed was also intro-
duced. To preserve the Kashima 34-m antenna, our policy
is to suspend operation (pointing the antenna toward the
zenith and applying the brake) if average wind speed has
risen above 10 m/s or if maximum wind speed has risen
above 15 m/s within the last 30 minutes. The routine
that we have developed monitors meteorological data at
KSRC and automatically points the antenna toward the
zenith and applies the brake when such wind conditions
are satisfied.

Table 5 Specifications of personal computer used in FS9

|	
CPU	Pentium 200 (MHz)
RAM	32 (MB)
Hard disk	SCSI 2 (GB) × 2; 1 unit for backup use
SCSI card	53c8xx
Network card	3c590
Video card	Stealth 64
OS	Debian GNU/Linux 2.0 (kernel 2.0.34)
Observation equipment control	GPIB (converts signals from serial port to GPIB sig-nals via National Instruments GPIB-232CT-A)
Antenna control	GPIB (National Instruments AT-GPIB)

Fivept (Latitude)

Fivept (Longitude)
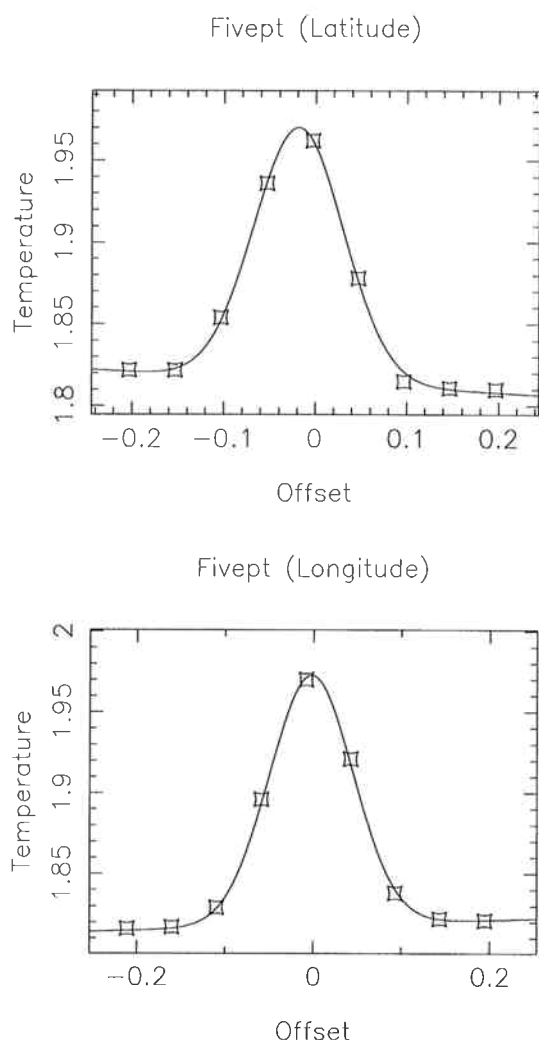
Fig. 11 Example of an offset observation

In addition to the above, work proceeds on various extensions related to the automation of receiver control, antenna initialization, etc. Because software is provided as source code, the FS9 system is very appropriate for carrying out this sort of extension work and obtaining feedback from other observation stations on newly developed functions.

3.9 ACU and angle encoder system

The Antenna Control Unit (ACU) at the time of antenna construction was operated by a board computer based on transistor-transistor logic (TTL). The reliability of this equipment, however, dropped over the years, and the ACU was upgraded to a new type called "AC3" in 1996. The AC3 allows for functional expansion through function boards like those used by personal computers. In addition, antenna control is written in the form of programs that are stored on EPROM, which means that programs can be upgraded by simply exchanging EPROM chips. The AC3 is configured so that function boards like the CPU board and position-input board can be inserted into connectors on the motherboard. This facilitates replacement of current boards by spare function boards in the event of a system problem.

The ACU features several modes of antenna position control. These are Stand By that applies the brake to motors and brings the antenna to a halt; Manual Rate (MAN RATE) that sends a command indicating a constant speed; Command Position (CMD POS) that controls the antenna so as to converge on the position indicated; and Monitor and Control (MAC) that performs remote control.

In the case of remote control, the ACU compares the value received from the Antenna Control PC over an RS422 interface with a 20-bit-resolution optical encoder value, and submits control voltage to a Direct Current Power Amplifier (DCPA) as needed to minimize the error obtained in the comparison. The angular speed of the antenna drive, angular acceleration, and other characteristics are controlled by the ACU. The motors are protected from excessive current and other problems by the DCPA in the ADC, by fast-acting fuses, etc.

"Hunting" occurs when a bit drops off due to an error in the encoder system, and tracking errors will occur if the encoder has been improperly installed. To minimize these problems, various improvements have been made to the 34-m antenna such as eliminating noise from the encoder power supply and improving a flexure plate that absorbs eccentricity at the encoder-installation axis.

The ACU and angular encoder system are equipment that suffer faults quite often and consequently hinder operation. Spare ACU and angular encoders (optical units, electrical units, power-supply units) are therefore prepared for the 34-m antenna. This enables system recovery to be achieved quickly in the event of a system problem and minimizes obstructions to observations. When upgrading the ACU, moreover, improvements can be made to a spare system that, after checking, can be substituted for the current system making for more efficient antenna maintenance.

3.10 Compressor system

In a cooled receiver, the system supplies compressed helium to a refrigerator called a "cold head" and absorbs heat in that expansion cycle under vacuum insulation to cool the LNA down to an extremely low temperature. Up to recently, two helium-gas (He) compressors out of three units manufactured in the U.S. have been combined and operated alternatively for use with three cold heads. These compressors, however, eventually became too old for use, and a switchover to alternating operation by two He compressors manufactured in Japan was made in 2000.

The He-compressor room employs a fan to expel the heat generated from a compressor to the outside. At first, this fan was situated at the top of the room to expel air in accordance with the natural upward flow of warm air (which meant that air was taken in from air holes at the bottom of the room). With this setup, however, sand and dust would be absorbed into the room by the air intake at the bottom of the room resulting in many compressor problems. We therefore decided to take in air from the top of the room (and expel air from the

bottom) and to install a simple air filter at the top air intake that could be replaced periodically.

In the 34-m antenna, the He-compressor room and the refrigerators installed on receiver dewar equipment are separated by 50 m or more, and the possibility exists of He-gas leaks due to He-pipe loss and deterioration due to exposure of the He-pipe itself. This is one disadvantage of a system that places the receiver at the primary focus.

3.11 Improvements to the sub-reflector 5-axes drive mechanism

A 5-axes drive mechanism is used to change the position of the sub-reflector in the 34-m antenna. This mechanism can control the X, Y, Z1, Z2, and Z3 axes and consists of a DC motor, an electromagnetic brake, a 1:6 speed reducer, and an actuator based on a worm gear. The position of the sub-reflector is read by a Linear Variable Differential Transformer (LVDT) and controlled remotely by a Sub-reflector Control Unit (SCU) in the AZ Room. Manual control can also be performed from the Sub-reflector Drive Cabinet (SDC). As for the electromagnetic brake, we found that burnout of its solenoid coil, though rare, was related to the manner of brake installation, and an appropriate modification was made. This sub-reflector 5-axes drive mechanism is placed in the most severe environment of the 34-m antenna, and for this reason, both the sub-reflector and drive mechanism are lowered together to the ground for maintenance using heavy machinery once every two years.

3.12 AZ rail periphery and bolt exchange

The 34-m antenna was constructed in 1987, and in 1992, abrasion on the wear strip located on the upper surface of the AZ rail became excessive and the running surface of the wheel was found to be worn down by about 1 mm. We therefore replaced the wear strip and polished the wear strip's base plate at this time.

On replacing the wear strip, we installed a stainless steel cover on the AZ rail that was previously exposed to the elements (Fig. 12). With this cover, the wear strip is no longer directly exposed to rain drops. We also coated the AZ rail with oil having wool grease as its main component. Being close to the ground, we knew that coating the AZ rail in this way could invite abrasion caused by dust and sand adhering to the oil. At Kashima, however, priority is placed on suppressing corrosion and the oil was applied for this reason. These measures have kept the antenna in good condition.

In 1997, a bolt that attaches the wear strip to the base plate of the AZ rail broke and was therefore replaced. In 2000, moreover, a new bolt that had been installed as part of periodic maintenance also broke. These bolts are hexagonal in shape and appear to break under repeated applications of load and stress. Our plan is to change the shape of these bolts and reinforce their neck section.

As it turned out, the bolt that broke in 1997 struck and damaged the scraper that removes obstacles on the wear strip. To therefore enable the wheel section to be visible, we changed the wheel-section cover to a stainless steel screen and also made it easy to open and close the
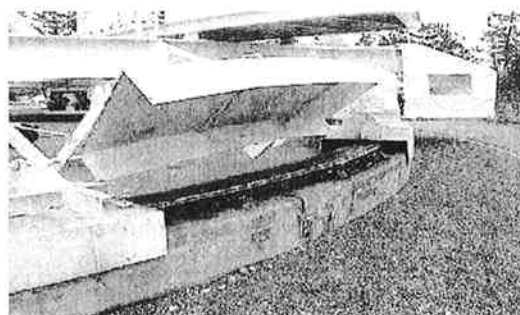
(a)
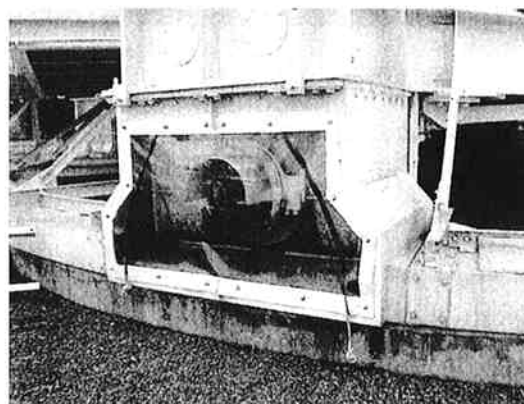
(b)

Fig. 12 a) AZ rail cover; b) wheel cover

rail cover. This change to a screen, however, meant that rain could penetrate the mechanism, and considering that the screen could not be easily attached or removed, we replaced it with a transparent vinyl cover in 1998. This modification makes it easy to see and inspect the wheel section and keeps out rain. As this example shows, detailed improvements are constantly being made to the antenna.

3.13 Drive motors

Four motors for AZ movement and two motors for EL movement drive the 34-m antenna. The four AZ motors make up two two-motor sets that are attached to two of the four wheels.

A motor drives a wheel through an electromagnetic brake, a chain coupling, and a cyclodrive for deceleration. As mentioned above, motors are installed in pairs, and torque bias is applied to prevent backlash.

The DCPA in the ADC amplifies velocity signals from the ACU to drive the motors. The logic board in the ADC applies torque bias to generate torque difference between motors.

Due to the fact that the AZ and EL drive motors are of the open type, problems related to corrosion and insulation occurred frequently, and we installed covers as shown in Fig. 13 to alleviate these problems. The AZ-motor cover is made of tent material and makes use of structural elements on the antenna. The EL-motor cover, on the other hand, is made of metal. Each type of cover

takes the need for motor cooling into account and includes a window to enable operators to check for abnormalities. Maintenance is performed once a year on armature, field coil, and commutator components and functions are maintained by preparing spare motors.

3.14 Improvements to the limit mechanism

Although originally thought of as something that could not happen in the 34-m antenna, cable wrap came to be damaged due to problems in the AZ limit system. To enable flexible observations to be made, the AZ axis is structured to allow rotation of ±359° with north as center. Its structure is also of a type that allows limit activation to be performed by determining clockwise (CW) and counterclockwise (CCW) zones in combination. In Kashima 34-m antenna even a large-turning CW (or CCW) value which is impossible in an ordinary antenna is obtained, which means that an error in zone determination can create a problem. Taking the above into account, we wound wire along the twisted cables and added a limit switch that activates at a twist of about ±270°, and also installed a limit switch that activates when an electric wire running along a twisted cable becomes severed. These new limit switches in combination with the original primary and secondary limits constitute safety equipment having a redundancy of four.
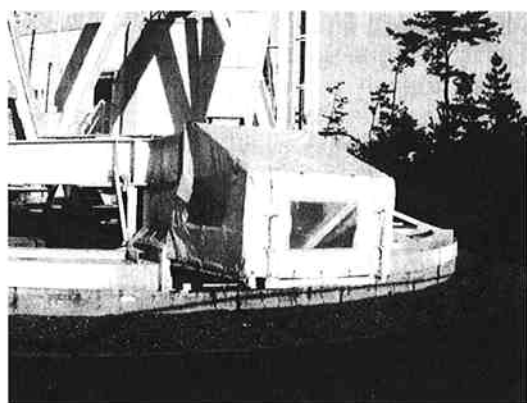
(a)
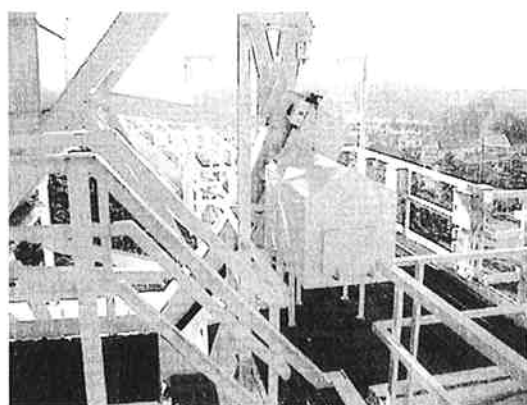
(b)

Fig. 13 a) AZ motor cover; b) EL motor cover

In the EL limit system, we have added a final limit considering that the structure of this system is exposed to wind and rain. This addition in combination with the original preliminary, primary, and secondary limits constitute a redundancy of four. Furthermore, these limits combined with the software limit in remote control performed by an ordinary computer constitute safety equipment having a redundancy of five.

A maintenance budget is provided to enable limit switches and the zone-determination mechanism to be inspected once a year. This periodic maintenance work checks first of all that the primary limit is not exceeded, and also that the final limit switch is not activated.

3.15 Conversion of antenna control lines to optical fiber

In the 34-m antenna, antenna pointing is performed on the antenna side according to the AZ and EL values received from the ACU. The Antenna Control PC sends out these values as the occasion demands. Originally, however, the Antenna Control PC would transmit RS422 signals over a metallic cable that could induce faults in the Antenna Control PC or ACU as a result of lightning. To prevent this from happening, we converted the cable from the Observation Room to the AZ Room to optical fiber in 1997. Since then, there have been no faults induced in the RS422 I/F because of lightning.

3.16 Installation of a ventilation fan in the AZ-twist basement

The AZ twist section is located underground and a pump is installed there to remove water from rain or other sources. This basement also includes a distribution switchboard, and we have installed a ventilation fan at the entrance to keep the room dry as well as a pressure fan to circulate the air. These improvements maintain a dry environment and eliminate worry with regard to oxygen deficiency, gas poisoning, and the like.

3.17 Release of operation schedule on the WWW

The operation schedule of the 34-m antenna was originally posted on a whiteboard at the Radio Astronomy Applications Section of CRL and centrally managed from there. In the case of joint experiments with outside institutions, checking on available antenna time with the

Fig. 14 Interactive 34-m antenna reservation screen by CGI on the WWW

schedule manager and applying for time had to be done over the telephone or by facsimile.

However, as periodic maintenance came to be performed and stable antenna operation achieved, and as antenna use by groups other than the Radio Astronomy Applications Section came to exceed 50%, it was decided to release the operation schedule on the World Wide Web (WWW). This facilitates reservations and schedule checking from the outside.

34m Radio Telescope Operation Schedule

http://www.crl.go.jp/ka/radioastro/plan34m.html

As shown in Fig. 14, a WWW Common Gateway Interface (CGI) is used here to process reservations for antenna use. With this system, there is no need to bother the schedule manager to check on available time, and in addition, collaborating researchers can directly check how observations are being allocated.

4. Remaining Issues

Budget permitting, the 34-m antenna is subjected to remedial painting and anti-rust processing every two or three years. Nevertheless, corrosion on the back structure of the main reflector is advancing and becoming a major problem for the antenna structure. In particular, corrosion is significant at the junction between the truss that extends radially from the center and the hoop on the circumference of the antenna. This corrosion is attributed to the continuous sea breezes and sulfur-dioxide gases typical of the coastal industrial region that Kashima is located in. Figure 15 shows the measures taken from 1998 to 2000 on about one-third of the sections in which corrosion has been advancing. Here, surface-preparation, reme-
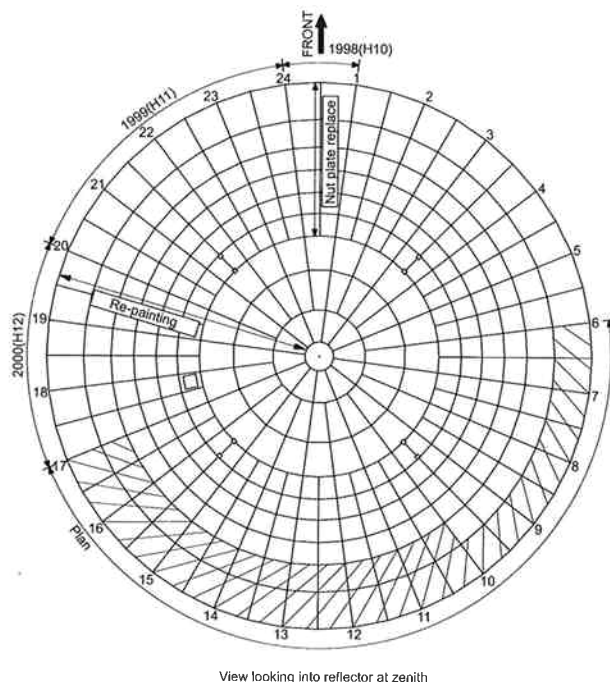
dial painting and welding repairs have been performed on the back structure. Corrosion is also occurring on the nut plates of the panel support that fixes the back structure and the main reflector, and we are replacing these by stainless steel nut plates in combination with remedial painting. Countermeasures are likewise being planned for corrosion that is expected to advance remarkably along the periphery of the antenna in the coming years.

5. Analysis of Antenna Usage

Figure 16 shows antenna usage frequency for a period of about one year starting in March 1999. The pulsar-timing observations are conducted by the Space and Time Measurements section at the Koganei Headquarters of CRL while VSOP and J-Net represent joint research with outside institutions. In these cases, operators are dispatched to KSRC from these institutions. As shown, the 34-m antenna is used for a wide range of observations including those associated with time comparison, radio astronomy, and geodesy and the development of gigabit equipment. In this way, the majority of observations have come to be executed by outside operators. The relative absence of problems, however, is due to periodic maintenance, which enables stable antenna operation, and to completion of the operating system. At other times, the antenna is used for the development, upgrading, inspection, repair, adjustment, etc. of equipment.

While almost all antenna functions can be controlled remotely, an inspection is always performed by a pre-operation check sheet before antenna operation. This inspection examines, for example, the appearance of the antenna, the AZ rail, the helium compressor, drive con-
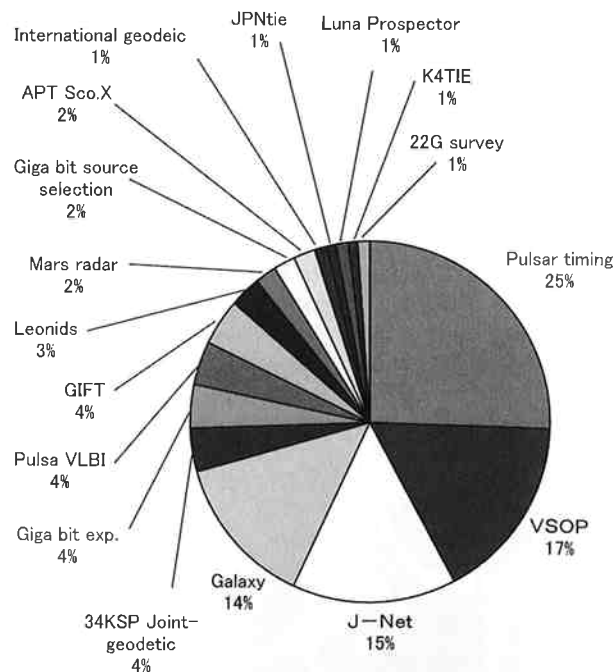

Fig. 15 Range of corrosion on the back structure of the antenna

Fig. 16 Frequency distribution statistics of the 34m antenna usage (period: Mar. 1, 1999 − Mar. 7, 2000, total number: 101)

trol equipment, receiver-system equipment, and equipment in the Receiver Room. The drive motors are also inspected during operation for excessive heat, abnormal noise, etc. These inspections are useful not only to ensure normal antenna operation and a successful observation but also to minimize system faults by early detection of abnormalities.

6. Operation System

Operation of the 45-m antenna at the Nobeyama Radio Observatory of NAO and that of the 64-m antenna at the Usuda Deep Space Center of the Institute of Space and Astronautical Science (ISAS) are supported by the manufacturers of these antennas. Operation of the 34-m antenna, however, is generally handled by members of CRL. A shortage of manpower, moreover, is resolved through the help of operators from joint-research institutions at the time of observations. Two antenna specialists have also been employed as part of the Cooperative System for Supporting Priority Research of the Japan Science and Technology Corporation (JST).

We rely on the antenna-import companies to perform periodic maintenance and repair work. Technically advanced matters, however, requires support from U.S. manufacturers, but replies to such requests usually take time.

7. Summary

In this article, we have described those sections of the Kashima 34-m antenna that have undergone changes since the antenna's construction with the aim of providing reference material for making VLBI observations with this antenna. We have also overviewed those sections of the antenna that have not been modified as an aid to understanding the overall antenna system.

As a result of obtaining a budget for regular mainte-nance and carrying out periodic maintenance and repairs, antenna reliability has improved and almost no observation failures have occurred over the last several years. This improvement in reliability has also allowed observations to be executed by outside operators and antenna resources to be used in a more efficient manner. In the coming years, ongoing maintenance will be just as important to high-reliability antenna operation.

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