GBT Memo No. 23

NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, WV

MEMORANDUM

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To: John Payne

From: Fred Crews and Rich Lacasse

Subj: **The Nobeyama 45-meter Telescope**

I. **Introduction:** We visited the NRO at Nobeyama, Japan during the week of 10/09/89 to find out about:

1) Active telescope surfaces.
2) Actuating systems for active surfaces.

The above 2 items deal mainly with the NRO 45-meter telescope completed in 1982. We were hosted by Nobuharu Ukita, the scientist in charge of the 45 m. We also had the opportunity to speak with Norio Kaifu, Masaki Morimoto, and Masato Ishiguro, scientists on the NRO staff. In addition, we spoke briefly with Osamo Sakakibara of Mitsubishi. Information we gleaned from conversations with these gentlemen is summarized below.

II. **General**

A. Environment: Nobeyama is located about 2.5 hours northwest of Tokyo in the mountains that run down the center of the island (approximate latitude: 36° north; longitude 139°; elevation 1400 m). The climate in Nobeyama is much like Green Bank as far as we could determine. There may be more colder clearer days. They observe about 7 months out of the year, spending the remaining 5 months on upgrade and maintenance. This is mainly due to unsatisfactory millimeter observing conditions. Wind velocity is <7 meters/sec. 75% of the time. Winds of less than 4 to 5 m/s are required for good pointing at 2.7 mm. Seven meters/second (15.56 mph) seems to be the wind velocity at which they would stop observing. They consider 10 meters/sec. (22 mph) to be high. Winds of 10 to 15 m/s cause about 10" pointing variation.

B. Panels/actuators: The surface is not active. The purpose of having actuators is to enable the setting of the panels, but not to control them. As a matter of fact, Dr. N. Ukita said that he considered an active surface dangerous because of the concern that a few panel actuators might not work; therefore, the active dish adjustment might not be reliable. The panels are not adjusted to desired position as a result of telescope position. They can only be adjusted one at a time, and the readout is a counter which

counts pulses generated as a result of rotation of the motor shaft. One pulse is equivalent to 10 microns of motion of the actuator output shaft. Therefore, this is only an incremental system not an absolute system. The actuators are controlled by a small computer and some sort of addressing tree.

C. Arrangement: The panels are not in rafts. In general, there is an actuator at each juncture of 4 panels. However, on some adjacent rows of panels, the inner panels are larger and fewer in number. On some of these, the support points are not in the corners; at worst, a support point is about one-third the width of the panel from the corner.

D. Panel Spacing: The panels are fairly uniformly spaced 3 mm apart. It appears that there is just a bit of rain channel provided by the side construction of the panels. Thus, a light rain would go on through the panel cracks, and a deluge would be channeled to the center of the dish.

E. Method of setting: The initial method of setting the telescope was by a specially developed, remotely controlled, laser ranging theodolite. The accuracy of this system is estimated to be about 170 μm rms, which is the largest error in the surface error budget. It was interesting to learn that this system works worst at zenith because of stratification of the air in the dish. Most measurements were made at other elevation angles. This method of setting has been abandoned, and all corner cubes are absent from the surface. They now use holography, and achieve about a 100 μm measurement error, but emphasize that it is very easy to misinterpret the data. They point out that improving their pointing will improve the holographic measurement since the locus of the sampled points will be more accurately known.

III. Actuators: The actuators, of which there are 700, support 4 adjacent panel corners for the most part.

A. Mounting: There is a 4 hole bracket that accepts the support for each of the 4 adjacent panel corners. This bracket is in effect moved up and down by motion of the actuator. An extension of the actuator protrudes through the 4 panel juncture, and has an accurately machined reference surface which may be used for individual panel setting among the four; it was also used for mounting corner cubes in the laser ranging measurement system. The base of the actuator is bolted either to the tops of the "nodes" of the backup structure or in some cases to intermediate backup structure by "U clamps". Separate differential bolts for each panel are individually adjusted for the individual height of each corner. The question was asked "how do you get all 4 panel points to be correct at the outset?" For panel to panel reference, there is a fixture that fits down over the top of the actuator stud and references to the machined surface mentioned above. It has dial indicators which are read by someone situated on some sort of small

portable bridge (to avoid deforming the panels being adjusted). Differential screws on the back of panel are adjusted by another person until the desired dial indicator reading is achieved. Each of the four panels are set by this method resulting in a setting of about 20 microns panel to panel, peak to peak we were told. The desired readings on the dial indicators are derived from contour maps of the actuators, made during panel testing.

B. Characteristics:

1. The total range of motion of the actuator is about 3 cm.

2. Rated load is 500 kg. It was pointed out that the worst problem for the actuators occurred when the wind load was added to the panel weight. (Fred lifted a panel and thinks it weighs about 65 lbs).

3. The actuators are operated by reversible ac brushless motors. They can only be driven one at a time. Therefore, after a measurement is made, it is a rather long process to adjust the entire surface (about 2 hours). The use of ac brushless motors sounds attractive for full time control for the GBT because of less likelihood of interference.

4. Travel rate: 10 μm/s.

5. The backlash is tested to be <20 microns. It is anticipated that wear should result in an additional 10 microns or less in 10 years of usage, averaging 3 cycles/day.

6. Frequency of usage: tested once a year.

7. Failure rate: 3 or 4 of the 700 fail during the yearly test, mostly due to connector problems or a failure in the optical chopper circuit which is associated with the motor.

8. Projected lifetime: 10 years at three cycles per day.

9. Sideload capability: The actuator supports the equivalent of one panel with its associated wind loading, in all orientations.

C. Readout: There is not a separate readout on each actuator. In fact, there is not a readout at all. Panels are adjusted by driving the motors "X" number of 10 micron steps. The system is only incremental, and in effect counts drive motor revolutions. There is no way to know that the panel has moved without making another holography measurement.

D. Reliability: The actuators are serviced completely by Mitsubishi. This is generally characteristic of NRO. They have a lot of work done by outside people; they seem to have a lot of industrial friends, and maintain a good working relationship with them. The failure rate is 3 or 4 failures per year out of 700 actuators. However, this is not very helpful information since they are so seldom moved. In a nutshell, they are only tested once a year. Our feeling is that the failures are most likely due to corrosion due to water entrapment although that was not indicated by NRO. We seriously doubt that there were mechanical or bearing failures.

E. Replacement: Replacing an actuator assembly is not easy, since all four panel points become free as the assembly is removed. To get to the actuator, a pathway to it has to be constructed from the main access to the backup structure. Then a board platform of some sort is jury rigged to facilitate access. Since the distance between the top chords and bottom chords of the backup structure changes for every row of panels, a prefabricated portable platform cannot be used. Apparently this problem has not happened frequently enough that anything more formal than this method of access has been done. It was absolutely unclear to anyone we talked to what the exact procedure was after the platform was assembled. We could see that taking out bolts and running the actuator all the way down might permit removal, but there was no obvious way to maintain the setting, or even to support the panels while a new assembly was being installed. It was stated that before the actuator is removed certain points are measured; after the actuator is replaced, it and the differential screws can be adjusted to try to reproduce these readings. The error in this procedure is estimated to be 100 to 300 μm.

F. Cabling: There were connectors at each actuator, the cables of which went to a junction box through a rubber bushing. Each junction box had 4 input cables (from each of 4 motors) and 2 larger output cables on rubber sealed feed-throughs going down off the telescope structure. We were told that the junction boxes were used as a means to shift power and readout within the 4 actuators. We don't believe that just because of the relative sizes of the input/output cables. We suspect that this is simply a scheme to combine four cables into two, thus reducing the number of cables that must go through the cable wrap. Unfortunately, we did not get to see the cable termination point and power supply/readout.

G. Further actuator notes: We were able to meet with the Mitsubishi engineer in charge of the 45 m telescope for a few minutes. He said that most failures were due to connectors being wet or corroded. Their connectors did not look very good for outside usage. Other failures were electronic failures having to do with the very simple readout system of chopper/LED/photo-transistor. He felt that there would be far less moisture failures if the motors were frequently used. He estimated that the actuators should be good for 10 years use at 3 cycles per day. This turns out to be remarkably close to 10,000 cycles, which is about the norm for this product.

IV. Panels

A. General: There are 9 rows of panels around the dish. The inner 6 rows are made of carbon fiber, and the 3 outer rows are made of aluminum. Both the carbon fiber and the aluminum panels are filled with aluminum honeycomb material making them 10 cm thick. There are several sizes of panels, they are trapezoidal, and roughly 1 meter by 2 meters. The estimated weight of a panel

is about 65 pounds. Mean surface accuracy of the carbon fiber panels is 55 μm while that of the aluminum ones is 70 μm rms.

B. Types:

1. Carbon fiber: These panels are composed of an outer shell of carbon fiber material 1 mm thick laid over a core of honeycomb aluminum. The appearance of the carbon fiber is as a woven cloth impregnated with a filler, all of which appears to be black, or charcoal gray in color. An aluminized conducting surface is sprayed over the carbon fiber. This is followed by two well controlled coats of flat white paint for spectral diffusion of the sun's energy. They noted that they had measured a 20°C rise in temperature when the telescope was pointed at the sun. About 190 panels had to be repaired this summer. The damage was due to water in the panel causing problems when frozen. The problem seemed to be due to microscopic holes in the panels which permitted water vapor to enter. This was a serious problem. If the NRAO uses this type of panel construction for the GBT, care must be exercised to prevent this happening.

2. Aluminum: The aluminum panels appear to be of similar construction and support as the carbon fiber except of course they are aluminum sheet.

C. Support: Panels are supported at the corners about 4 cm in from the corner with studs threaded into a thimble mounted in the panel. From the top of the panel, one sees a slotted bolt head, and a spanner nut which is assumed to act as a lock. The exceptions to this are the inner row and outer row which have their inside and outside mounting holes respectively inserted some 35 cm in from the edge. This overhang has been a problem, and has resulted in some panels being damaged due to service personnel walking in these areas. (These panels have been replaced.) It is to be noted that soft tennis shoe type soles are acceptable for walking on their surface. To avoid distortion of the panel due to unequal thermal expansion, there are 3 types of support points built as a part of the panel hold down bolts. One support is large and rigid. Adjoining corners to the rigid one have a support stud that is thin in one direction, thick in the other. These are turned so that their flats face the rigid support. The final support is thin and relatively easy to bend in any direction, and is diametrically opposite the rigid support. These supports are made of hard brass or spring brass.

D. Insulation/isolation of panels: Attached to the backs of the panels are 6-8 cm by about .5 cm studs of stainless steel. These are on about a 20 cm grid and serve to support 2 cm thick insulation with the vapor barrier turned toward the backup structure (away from the panel). These serve to isolate the panels from the backup structure. It is desired that the panel be at ambient throughout the panel so that it is insulated from the backup structure environment. (The backup structure is also kept

at ambient, but has a much longer time constant.) Additionally, strips of foam seal are inserted at the edges to form a water seal to reduce the chances of water being trapped in the space between the panel and the insulation.

V. Backup structure: The backup structure uses the homology design. Deviation from the best fit paraboloid over elevation is < 90 μm rms. The structure emanates from the central steel hub, and has definite nodal shapes along the ribs. The ribs and backup structure (cross bracing, etc.) are made of galvanized pipe fitted together by either welding or with bolt mounted flanges. Critical length pipes, which seem to run circumferentially, are fitted with flanges whose ends are carefully machined, both for length and angle. Carefully machined mating flanges are provided for these on the nodes. The node, pipe and flange construction, it is claimed, made the analysis of the backup structure straightforward and resulted in good homologous performance. The backup structure is enclosed on the back with about 1/32 inch aluminum radiation shields, insulated from the backup structure, which serve to help establish thermal equilibrium within the entire backup structure. Since galvanize is a good heat absorber, the backup structure would tend to reach equilibrium rather quickly. To enhance this and keep stratification of the temperature of members to a minimum, attic sized fans are placed in a circumferential fashion to keep the air moving in the reasonably confined backup structure area. There is no attempt to waterproof this area and cracks between the radiation covers are about 5 mm. One of the things that can quickly create a problem is huge blocks of ice forming in the backup structure. They have had this experience.

VI. Autocollimator: A master collimator is at the heart of the pointing system. It is situated at the intersection of the telescope's axes, atop a 23 meter cylindrical steel pipe. The pipe has a radiation shield surrounding it, and ambient air is forced through it to avoid temperature differentials. Recent measurements with inclinometers showed no measurable tilt (<1") in the pipe, for varying telescope azimuth angles. Measurements of the collimator revealed about a 1" error. This stability was achieved by improving the thermal environment of the device, mostly by adding air deflectors and insulation. The collimator presently on the telescope is a recent replacement for the original one. Its cost is $1M, about 50% of which is NRE; we could probably buy the same unit for $0.5M.

VII. Feed legs: Each of the three feed legs consists of four main tubular members stiffened with cross bracing. The two lower members are almost touching for most of their length, while the two upper ones are separated by roughly one meter, resulting in a triangular cross-section. Each of the tubular members is surrounded by a radiation shield. Air pulled from the backup structure cavity is blown through each tubular member.

VIII. Miscellaneous:

A. Stow position oscillation: One additional statement needs to be made regarding this telescope, and it is made here because it doesn't fit any category of this report. There is some sort of oscillation problem when moving or using the telescope near the stow position. We have conflicting notes on this. However, it seems to be a problem inherent in the design.

B. Tertiary support: The support for the tertiary contributes to pointing errors. The support consists mainly of a hollow tube hung inside the central hub. It ties into the hub near the surface of the dish, and solar radiation can differentially heat the tube causing the tertiary to move relative to the primary and secondary. There appear to be radiation shields covering the tube, but apparently this is not enough.

C. Optics: Losses in the optics are not well studied. The measurement is difficult to make. The performance at 100 GHz is similar to that of other telescopes at this frequency, so the loss at this frequency must be small. Any information about performance at 10 GHz somehow got lost in the translations.

They basically saw our rationale for offset optics in the GBT. They suggested we study the polarization properties of such a configuration carefully.

D. Spectrometer: Two acousto-optic spectrometers are in operation at the 45 m. A high-resolution AOS achieves 160 MHz bandwidth and 8192 channels. A broad-band unit achieves 2 GHz bandwidth and 16384 channels. Each can be operated as four independent AOS systems. Stability is typically 0.3 channels, and calibration is required every few months. Interestingly, it is expected that future developments in wide-band spectrometers at Nobeyama will use digital techniques, as very high sampling rate (> 2 GHz) A to D converters are now becoming available to them.

VIII. Summary: It has been found not necessary to provide an active surface at the NRO 45-m telescope due to the homology design and careful attention to isolation/insulation. Many of the things that worked were passed on to us by the competent NRO staff. Actuators have made panel setting much easier and reliable. They are sold on carbon fiber panels since they this summer added one more row, and intend to eventually replace all the aluminum panels. Again, we thank the NRO staff for their help. A special thanks to Dr. Ukita and Dr. Kaifu.