MILLIMETER ARRAY
MEMO NO. 78

Report On Visit To Hat Creek

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INTRODUCTION

On the 4th and 5th of November we visited the Astronomy Department of U. C. Berkeley and the Millimeterwave array at Hat Creek to look at the design and fabrication of the new antennas for the BIMA array. The array currently has three 6m diameter antennas, three more are well under construction, and a further three are partly fabricated. Some tests have been done on the pointing and drive system of the first new antenna, using an optical telescope, and the first three rings of panels have been installed. We also discussed their progress in 4K refrigerator development, and their receiver plans.

ANTENNAS

Mount

The mount is an all steel welded structure supported on three legs. Most of the surfaces exposed to the sun are insulated with aluminum-faced foam (~2" thick).

Drive System

The azimuth and elevation drives are essentially the same. A stepper motor, commanded directly from the Sparc 2 control computer, drives a rotary actuator through a timing belt which removes some of the roughness associated with the steps. The rotary actuator, made by Dogen, is a planetary friction drive with zero backlash. A flexible coupling connects the rotary actuator to a stainless steel 100mm diameter roller which is held against a large ring (~1.8m diameter?) in the azimuth drive, or a stainless steel arc for the elevation drive. The roller is mounted on a tangent arm which allows radial but not tangential movement of the roller. Pinch wheels press on the rear of the flange of the arc or ring to provide the required pressure against the roller. The friction should be sufficient to hold the antenna in winds up to 60mph — it would be stowed before the wind speed exceeded that. Slewing speeds are on the order of $1^\circ.\mathrm{sec}^{-1}$.

So far the tests have been very positive. The only significant problem has been with the bearings for the roller which were designed for radial forces only and which failed due to unanticipated thrusts. These bearings will be replaced with a more suitable type.

Encoders

Inductosyns are used for elevation and azimuth encoders. These have a 2° cycle which is resolved into 16 bits and the ambiguity is removed by using a resolver to give a total of 24 bits or about 0.1 arcsec resolution. The electronics for the inductosyns are designed and built at Berkeley. The two phases are digitized and the angle is calculated by the Sparc 2 control computer. To test them they run two in opposition and look at the differences in the outputs. Typically there are a few arcseconds difference between the two encoders, and the repeatability is 0.2 arcsec. The azimuthal encoder rotates with the telescope, and the elevation encoder is mounted in the receiver cabin and moves in elevation.

Backing Structure

The backing structure was designed and fabricated by TIW, and is a welded steel structure. The members have a square cross-section and are joined by flat webs. Fabrication accuracy is on the order of 5mm. Structural analysis predicts that the deflections under gravity will be about 10 - 15μ, and wind deflections of a similar magnitude. The primary focal ratio is 0.42 in keeping with the existing antennas, the first of which was a commercial item.

Thermal Behavior: Thermal behavior is currently under investigation, and measurements have been carried out on the existing antennas. During the day temperature gradients on the order of 1K are observed giving surface errors of 10 - 15μm. If there is wind blowing through the structure lower temperature gradients are observed. The backing structure will be enclosed with aluminum faced insulation and fans may be used to provide circulation to bring the backing structure to a uniform temperature.

Secondary Support Legs

There are three legs supporting the secondary mirror. These are arranged in the form of an inverted 'Y'. Each leg is made as a truss with square cross-section upper and lower members and diagonal bracing between them. The legs are supported just outside the rim of the primary to minimize blocking (~1% of the area). They are pin-jointed to the backing structure and are therefore an important factor in the stiffness and strength. Squirrel cage fans blow air up through the tubular members to reduce temperature gradients. The air is sucked in through the backing structure and exhausted through the top round the secondary mount to keep as much of the antenna near a given temperature as possible. Insulation is wrapped round the legs to minimize insolation.

Panels

Cast machined panels with an area of about 0.5m^2 are used (the outer panels are 0.69m by 0.64m). The castings are made by TIW and panels with cracks or voids are rejected rather than being welded. An independent machinist mills the final surface. The numerically controlled milling machine has a specified accuracy of 5μm rms and is laser-aligned and temperature stabilized to achieve this. The castings are placed on the machine in special jigs which hold them at an angle to the base (they are set at an angle so that they do not exceed the travel of the machine bed). A diamond-tipped fly cutter is used to cut in radial strokes. The distance between the strokes is chosen to keep the peak less than 25μm. The resulting scalloping tends to scatter solar infrared and visible radiation over an angle of about 5° reducing heating effects at the primary and secondary foci. One rough cut is made followed by two fine cuts. Heat treatment is applied after the rough cut. During the final cut the attachments to the mounting jig are completely removed apart from one point at the lower edge!

Since the cost of measuring panels is comparable to the machining cost only 20% are checked. The measuring machine has an accuracy of 5μm, comparable to the numerical mill, and this is also the rms measured for the panels when the measurements are made in the valleys of the scallops. If the shapes of the scallops is taken into consideration the overall accuracy is about 8 - 10μm. In the analysis of the panel figure there are three free parameters in fitting the paraboloid, namely tilts about orthogonal axes in the panel plane and a piston movement. Once these terms are removed it is sometimes found that the panel has a saddle shaped profile which is thought to be due to slow thermal drifts during machining. The panels have a four-point mount and this allows the saddle shape to be completely removed from the panel. Each panel is mounted by its corners and can be adjusted from the front. The supports are attached to oversized holes on the backing structure to permit accurate location, and spherical washers are used to avoid undesirable over constraints. Plastic springs hold the panel up against the adjustment screws.

Panels are separated by gaps of 1.2mm nominally, though this can change by about 0.5mm due to differential thermal expansion.

Secondary Mirror

The secondary mirror is machined aluminum. Currently an axial and a radial (north-south) translation are implemented, but a nutating mechanism is also planned. The secondary focal ratio is about 4.8

Receiver Cabin

The cabin houses receivers directly at the Cassegrain focus. It is approximately a cube 2m on a side, though it takes a conical form in the region of the primary vertex. One receiver will be mounted on points attached to the structure. A rack mounted on linear bearings is provided for electronics chasses, such as the communications module. Temperature regulation is to within about 1K. Around the cabin is a platform for access to the encoders etc, and the refrigeration unit for water and the cryogenics compressors are located there.

Cable Wraps

The azimuth wrap uses a large linked chain (similar to a bicycle chain) folded between an inner cylinder which rotates in azimuth and an outer cylinder which is fixed. The cables are tied to the chain. Elevation wraps use a drum over which the cables are hung.

Weight

The total weight of the structure is about 30 ton.

Cost

The following are items for which costs are accurately known. There are several other costs such as outfitting the antennas with electronics, mounting and setting panels, etc. which have not been included as there are no hard figures for these.

Structure:	Mount, Azimuth bearing, Azimuth cablewrap, Elevation pillow blocks, Backing structure, Drives (excl. motors), Stainless steel roller rings, Gear box — $196k
Panels:	Casting, Machining, not including patterns, design

		— $44k
Drives:	Stepper motor and control	— 2x$4k
Encoders:	Rotor and stator, Circuit, Mounting,	— 2 × 12k
Secondary:	Mirror, Mount with focus drive	—$8k
Insulation:	Material, Labor	—$7k
TOTAL:	$287k	

Miscellaneous

The antenna design is marked by attention to details, such as ducting warm air from parts of the mount down to the cable wrap to retain the cable flexibility when the ambient temperature is low. We have a set of photographs of the antennas and many of the details.

RECEIVERS

It is planned to have four receiver channels in a single dewar. These would be single polarization receivers covering the ranges 70 - 90GHz, 90 - 115GHz, 140 ± ?GHz, and 220 - 270GHz. Eventually they will use SIS mixers, but initial tests might use Schottky diode mixers. Each receiver band has its own window and all the receivers look towards the secondary — selection is made by repointing the antenna. LO power is injected optically through a dielectric beam-splitter from a Gunn or a Gunn followed by a multiplier.

REFRIGERATORS

Development of 4K systems is focused on Gifford-McMahon refrigerators with Er_3Ni in the final displacer. The latest setup uses a CTi Model 350 refrigerator for the first two stages, and the end from a Model 22 for the final stage. In fact only the cylinder of the Model 22 is used and the displacer is specially fabricated. In order to get round problems of blow-by in the seals the displacer is an extremely fine fit in the cylinder and no seals are used. Approximately 30g of Er_3Ni are used and the particles are selected to be greater than 9μm in diameter. Optimum cooling is obtained by reducing the cross-head speed to about 43 rpm.

With loads of 8W on the 1st stage, 0.5W on the 2nd stage, and 50mW on the 3rd stage the third stage temperature runs at 4.43K. The temperature on the third stage varies over the cycle by about 0.2K, though this would be reduced by additional mass of receiver components.

Future plans include a system based on a CTi Model 1020 cross-head.

CONCLUSIONS AND COMMENTS

The BIMA antennas have similar specifications to the proposed mmA antennas, though the size, surface accuracy and pointing precision are all somewhat less. Consequently they appear to be a good baseline for evolving the mmA design. Two of the most critical aspects of the mmA design are the thermal stability and the pointing accuracy., and we would like to work with Berkeley on both of these aspects. For the thermal studies Jack Welch's group is instrumenting their antennas with thermistors and this will be of value to us. the 12-m is also equipped with temperature sensors, but is a less suitable model because it is more different in size from the mmA design, is enclosed in an astrodome, and is less accessible because of full-time use for astronomy. We therefore propose to collaborate closely with the Berkeley group to determine thermal limits to pointing and surface accuracy.