MMA Project Book, Chapter 4.

ANTENNAS

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Revision History:

1998-08-23: Added information from PDR; test plan, earthquake spec, receiver cabin power and mass requirement.
1998-09-01: Added Summary, corrected typo in fast switching time spec.
1998-09-01: Added requirement for metric compatibility, electrical supply voltage and frequency.
Added chapter number to section numbers.
1998-09-18: Changed resonant frequency requirement in 4.2.8; added 3 phase voltage in 4.2.2.

Summary

The MMA is currently planned to consist of at least 30 antennas, each of 10 m diameter. The number and/or diameter of the antennas may change if the MMA is combined with the LSA project to form a larger array. The principal requirements for the antennas are shown in Table 4.1.

Table 4.1 MMA antenna principal performance requirements.

Configuration	Elevation-over-azimuth mount, Cassegrain focus
Frequency range	30 GHz to 900 GHz
Reflector surface accuracy	25 microns, rms
Pointing accuracy (9 m/s wind, 30 min between calibrations)	1/30 beamwidth at 300 GHz , rms (0.8 arcsec)
Fast switching (settle to 3 arcsec pointing)	Move 1.5 deg on sky in 1.5 seconds
Phase stability	7 microns rms
Close packing	1.25 dish diameters between azimuth axis
Solar observing	Allowed
Transportability	Transportable on a rubber-tired vehicle

The antennas will be designed and built by a commercial company. The principal goals to be achieved by the end of the MMA Design and Development (D&D) Phase are to select a contractor and to complete the design and fabrication of a prototype antenna. The principal milestones required to achieve this goal are shown in Table 4.2.

Table 4.2 Principal milestones for antenna work during D&D Phase

Vendors information meeting	September, 1998
Issue Request for Proposal (RFP)	January, 1999
Receive proposals	April, 1999
Evaluate proposals and place contract	July, 1999
Design completed by contractor	June, 2000
Deliver antenna to US test site	June, 2001

4.1. Introduction

This chapter presents the current state of understanding of the performance requirements for the MMA antenna elements and describes the current strawman design concepts which will satisfy these requirements. Also described are the current plans for the procurement and testing of the antennas.

The "antenna" subsystem of the MMA is here defined to include the following equipment:

10 m diameter primary reflector including tripod or quadripod subreflector support legs.

Secondary reflector and its servo-controlled positioning platform, including nutation.

A receiver cabin and its HVAC system.

Alt/az mount, the drive systems on the mount and the servo-system controller for the drives.

Metrology instrumentation such as temperature probes, tiltmeters, laser metrology systems, etc.

Power distribution cabling on the antenna and the cable wraps for these cables.

Platforms for mounting auxiliary equipment such as cryogenic compressors.

Antenna foundation design but not fabrication.

Antenna transporter vehicle.

The following equipment is not included as part of the "antenna" subsystem and must be supplied as part of another subsystem:

Cables and special cable wraps required for IF and LO signal distribution. The antenna will provide suitable mounting interfaces for this equipment.

4.2. Specifications and Requirements

4.2.1 Operating Environment

The following operating environment defines the environment on the MMA site in Chile. The first few antennas will be tested at a location in the Continental US and it is possible that all antennas will be assembled and undergo preliminary testing at San Pedro de Atacama (altitude 2440 m). Before ordering the first antennas, these environmental specifications must be reviewed to ensure that they are adequate to ensure safety of the antenna at these alternate test location sites.

4.2.1.1 Location: Northern Chile, latitude -23d01m S, longitude 67d45m W.

4.2.1.2 Altitude: 5000 m (16400 ft) The barometric pressure at this altitude is 55% of its sea-level value.

4.2.1.3 Maximum Wind Velocity: The antenna must survive 65 m/sec (130 mph) without damage when positioned in its stow position.

4.2.1.4 Temperature: The antenna must operate correctly in the temperature range -20 C to 40 C. The annual average temperature on the site is -4 C.

4.2.1.5 Precipitation: Annual precipitation on the site is in the range 10 cm to 30 cm per year. Most of this falls as snow but thunderstorms do occur and so brief periods of heavy rain and hail are possible. The antenna must be designed to survive, without damage, the following conditions: maximum rate of rainfall 5 cm/hr, hailstones 2 cm diameter, snow load 100 kg/sq.m on reflector surface, radial ice on all exposed surfaces 1 cm. Surface heating to prevent snow and ice buildup not required.

4.2.1.6 Humidity: The monthly average humidity in the summer (January) is 53% and in the winter (June) it is 31%. The annual average is 39%. The monthly average water vapor pressure in the summer (January) is 4.0 hPa (4 gm/sq.cm) and in the winter (July) it is 1.2 hPa. The annual average is 2.3 hPa.

4.2.1.7 Insolation: The site location on the southern tropic, the high altitude and low water vapor result in insolation rates amongst the highest in the world. The median midday solar flux in the wavelength range 0.3-60 micrometers for the months of December and June are 1290 w/sq.m and 840 w/sq.m respectively. Ultraviolet radiation will be approximately 70% higher than at sea-level.

4.2.1.8 Lightning. Thunderstorms occur on the site so the antenna must be equipped with a lightning protection system.

4.2.1.9 Dust and Grit. The site ground surface is volcanic soil and gravel with no vegetation of any kind to stabilize the surface. It is likely that wind-blown dust and grit will be a factor for machinery operating on the site but this problem has not yet been quantified.

4.2.1.10 Earthquake. The MMA site is in a seismically active zone, but the source of the earthquakes, the tectonic plate interface, is more than 100 km below the surface so that the strength of the earthquakes is lower than the strength experienced closer to the Chilean coast. Design for 0.3G horizontal or 0.3G vertical acceleration.

4.2.2 General Configuration

The antenna will be a symmetric paraboloidal reflector, of diameter 10m, mounted on an elevation over azimuth mount. Subreflector support legs will be either tripod or quadripod configuration. A reflector surface consisting of machined aluminum panels is preferred. The reflector surface will be mounted on a carbon fiber reinforced plastic (CFRP) reflector backup structure (BUS). The BUS could be built completely of CFRP or could consist of CFRP struts connected by metal nodes. The tripod or quadripod will be made of CFRP. The reflector surfaces of the antenna will not be painted.

All drawings will have metric dimensions. All fasteners will be metric. The use of standard metric cross-sections for construction materials is preferred but will not be required if it results in a cost increase.

The supply votage for the antenna will be 220 v (single phase), 380 v (3 phase). All electrical systems must operate correctly on both a 50 Hz or a 60 Hz supply.

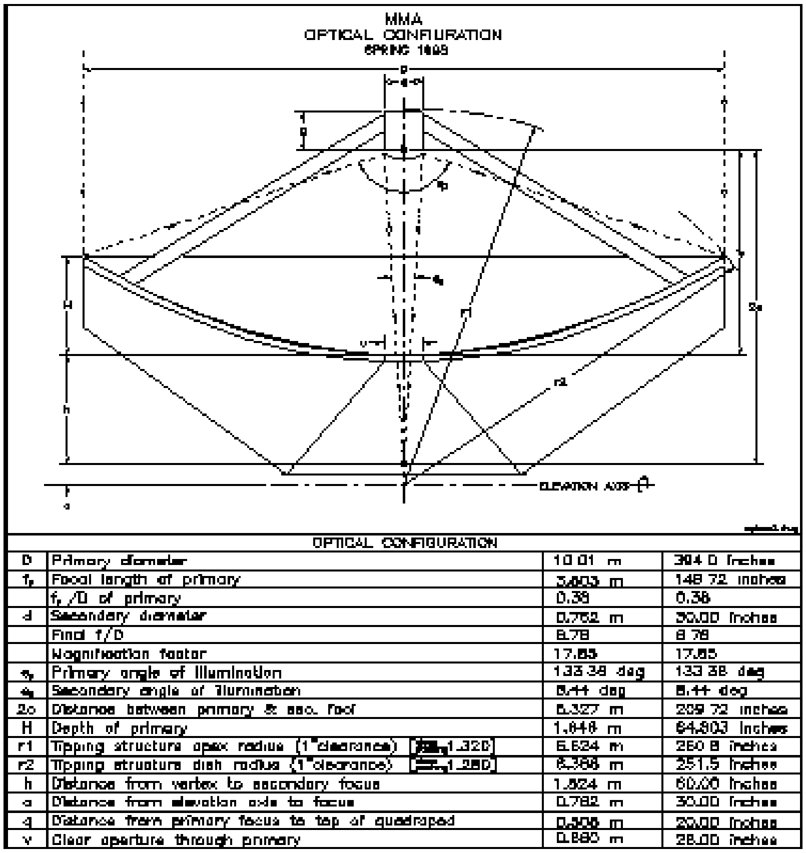
The antenna will be designed so as to conform to all relevant Occupational Safety and Health Administration (OSHA) and Chilean safety codes.

4.2.3 Reflector Geometry

The receivers will be located at the secondary focus of a Cassegrain geometry. A strawman design for the Cassegrain geometry is shown in Figure 1 (taken from Lugten (1998)) but there is still flexibility to make changes to this layout.

4.2.4 Range of Motion

Antenna foundations will be constructed so that the azimuth axis of an antenna is parallel to local gravity at the pad. For observations close to the zenith this will result in a difference in parallactic angle between antennas.



OPTICAL CONFIGURATION			
D	Primary diameter	10.01 m	394.0 inches
f_p	Focal length of primary	3.803 m	148.72 inches
	f_p/D of primary	0.38	0.38
d	Secondary diameter	0.762 m	30.00 inches
	Final f/D	8.78	8.78
	Magnification factor	17.85	17.85
θ_p	Primary angle of illumination	133.38 deg	133.38 deg
θ_s	Secondary angle of illumination	8.44 deg	8.44 deg
2a	Distance between primary & sec. foci	5.327 m	209.72 inches
H	Depth of primary	1.648 m	64.903 inches
r1	Tipping structure apex radius (1"clearance) [1.320]	6.624 m	260.8 inches
r2	Tipping structure dish radius (1"clearance) [1.280]	6.388 m	251.5 inches
h	Distance from vertex to secondary focus	1.524 m	60.00 inches
a	Distance from elevation axis to focus	0.762 m	30.00 inches
q	Distance from primary focus to top of quadrapod	0.508 m	20.00 inches
v	Clear aperture through primary	0.660 m	26.00 inches

Figure 1 Strawman MMA antenna Cassegrain Geometry

Minimum elevation angle for observations: 0 deg

Maximum elevation angle for observations: 125 deg. Cone of avoidance at the zenith: 0.2 deg in radius for normal sidereal tracking. Because of the high velocities and accelerations required for fast switching or on-the-fly mapping (see section 4.2.8 below) there will be a region around the zenith, probably about 30 deg in radius, where azimuth switching times are degraded .

Stow position for wind survival: elevation 0 deg (this position was chosen so that, during a winter storm, the reflector can be oriented with its back into the wind to prevent build up of snow and ice in the dish. In the event that the close packed array configuration requires a higher limit than 0 deg. (see Section 4.2.11 below), the high wind stow position will be this higher limit.

Stow position for maintenance: zenith (this position was chosen to prevent an antenna undergoing maintenance from mechanically interfering with an adjacent antenna in the most compact array).

Range of azimuth motion: 270 degrees either side of due north.

4.2.5 Reflector Surface Accuracy

The surface accuracy will be no worse than 25 micrometers rms, including the subreflector contributions. This will provide an antenna surface efficiency of 91% at 300 GHz and 41% at 900 Ghz. At night this accuracy is to be achieved in a wind of 9.5 m/s which is the 90th percentile wind for nighttime (2000 hrs to 0800 hrs) observing. During the day this accuracy is to be achieved for any orientation of solar illumination in a wind of 6 m/s. During the day the focus can be calibrated astronomically every 30 min.

The final, precision measurement of the surface will be done using holography. Reflector panels will be adjusted manually from the front side of the reflector with the antenna pointed at the horizon and the mechanic supported on an external platform or cherry-picker. The panel adjusters will be calibrated so that an adjustment point can be moved with a resolution of 5 micrometers without needing a dial-gauge or other motion indicator. A full surface adjustment must require no more than 16 person-hours of work.

4.2.6 Pointing Accuracy

An absolute pointing accuracy is required of 1/30th primary beamwidth rms at 300 GHz, which corresponds to 0.8 arcsec. At night this accuracy is to be achieved in a wind of 9.5 m/s which is the 90th percentile wind for nighttime (2000 hrs to 0800 hrs) observing. During the day this accuracy is to be achieved for any orientation of solar illumination in a wind of 6 m/s. During the day the pointing can be calibrated astronomically every 30 min if required to meet the accuracy requirement.

4.2.7 Metrology

Provision will be made in the antenna design for inclusion of metrology equipment which will allow antenna pointing to be corrected for structural deformation caused by wind or thermal loading. This equipment will be included on the prototype antenna both to evaluate the performance of the antenna and to determine if the metrology equipment is required on the production antennas. Metrology systems to be considered for including in the antenna include: a laser/quadrant-detector system to measure quadripod movement, tiltmeters, temperature probes, laser/retroreflector systems and an IR camera for offset-pointing on stars.

4.2.8 Fast Motion Capability

Two observing modes require the MMA antenna to have special fast motion capabilities: fast switching phase calibration and on-the-fly total power mapping.

Fast switching: The goal is to have the antenna move 1.5 degrees on the sky and settle to within 3 arcsec pointing error, all in 1.5 seconds of time. A possibly acceptable upper limit for this switching time is 2 seconds. It is expected that the switching acceleration profile will be carefully designed so as to avoid exciting the lowest structural resonant frequency of the antenna, in which case the lowest resonant frequency should not be lower than 8 Hz. The maximum velocity and acceleration required for fast switching are 3 deg/sec and 12 deg/sec/sec on the sky respectively, with both axes able to move at this rate simultaneously. It is expected that this velocity and acceleration will be achievable in azimuth only for zenith angles greater than 30 deg (this implies maximum azimuth velocity and acceleration of 6 deg/sec and 24 deg/sec/sec respectively).

Analysis of the expected use of this fast switching mode (Holdaway, 1997) indicates that the antenna should be designed to survive 30-50 million cycles of fast switching during an assumed 30 year life.

Peak electrical power demand during fast switching observations will not exceed (TBD) kw/antenna.

On-the-fly mapping: In this mode the antenna will scan at a rate of up to 0.5 deg/sec across a large object, several or many beamwidths in size, and then turn around as rapidly as possible and scan back across the source in the opposite direction. A maximum acceleration of 12 deg/sec/sec is required for the turn around. While the antenna is scanning across the source the antenna position must be recorded at a rate sufficient to provide an angular sampling interval on the sky of wavelength/(2D) radians. For 0.5 deg/sec motion and 900 GHz observations this requires antenna position readout every 2 msec. The antenna positions should be accurate to 1 arcsec. As the antenna tracks across the source it is not necessary for the position at any time to be precisely a precommanded position; it is sufficient to simply know where the antenna is actually pointing and all antennas need not point precisely at the same position.

A third observing mode requiring motion of the antenna faster than sidereal tracking rate is on-the-fly interferometric mosaicing, in which interferometry data is taken while the antenna is continuously scanning across the source. It is expected that the antenna velocity will be only one-tenth of its mapping-on-the fly value (see previous paragraph), but in this case all antennas must point to the same position at the same time to within 1 arcsec rms.

Fast slew to a new source position: 1.5 deg/sec elevation, 3 deg/sec azimuth. These velocities are less than the maximum velocities specified above for the antenna in fast-switching mode. This is because fast motion for fast-switching is required with low duty cycle whilst slewing could last for many seconds possibly resulting in motor overheating.

4.2.9 Subreflector Position Control

The subreflector will be supported on a platform which allows movement in all 3 linear directions. The precision of the mechanism will be adequate to allow the subreflector to be positioned, under computer command, with sufficient accuracy to prevent gain loss of more than 1% at 900 Ghz due to focus, comatic or astigmatic aberration. Position will be correctable on timescales of tens of seconds.

In addition to the above listed linear motions the first antenna will also be equipped with a subreflector nutator which will allow beam throws of three beamwidths at 86 GHz (4.3 arcmin) at rates up to 5 Hz in the cross-elevation direction only. The decision as to whether all antennas will be equipped with nutators will be made after testing the first antenna.

4.2.10 Phase Stability

Phase errors caused by variations in the propagation pathlength through the antenna can be rapidly or slowly varying. Fast phase changes are primarily caused by the wind and the peak pathlength variation in a 9.5 m/s wind must be no more than 7 microns. Slow phase changes are primarily due to variations in the temperature of the antenna and the goal is to keep these phase errors small enough so that the residual errors after an astronomical phase calibration every 3 min are small enough to allow observations at 900 Ghz.

4.2.11 Close Packing

In the smallest array the antennas must be placed close together. The goal is to be able to place the antennas within 12.5 m (1.25 D) of each other without any possibility of the antennas hitting each other, no matter what the relative orientation of the two antennas. An acceptable fallback on this requirement would be to have no possibility of interference for elevations above 20 deg. In the event that it proves necessary to have a higher elevation limit of this type when antennas are in the close packed configuration, an electronic interlock on the antenna pad will ensure that the higher limit is activated.

4.2.12 Solar Observing

Direct observations of the sun will be allowed. All surface accuracy and pointing requirements must be met while observing the sun and a suitable surface treatment of the primary reflector surface must be provided to prevent solar heating damage of the subreflector or its support legs. When observing the sun the solar heating of the secondary focal plane must be less than 100 watts.

4.2.13 Low Antenna Noise

Contributions to system noise from the antenna, due to such mechanisms as scattering of ground noise into the feed and resistive loss of reflector surfaces, will be minimized as much as possible without compromising the surface accuracy and pointing requirements. Design features to be considered to achieve this goal include supporting the subreflector support legs close to the edge of the reflector, shaping the underside of the support legs to reduce ground pickup and locating the feeds at the Cassegrain focus to avoid the need for tertiary reflectors.

4.2.14 Transportability

To move the antennas from one array configuration to another the antennas will be picked up and carried on a transporter vehicle which runs on a gravel road on rubber tires. The transporter with an antenna on board will be able to negotiate a 15 % grade, turn a corner with a minimum turning radius of 10 m and travel at 10 km/hr on the flat and 5 km/hr up a 10% grade. An unloaded transporter must be able to travel at 20 km/hr on the flat. The transporter must be able to safely move an antenna in winds up to 16 m/s (this is approximately the 95th percentile for the winds on the site at 1600 hrs local time, the time at which the winds are maximum each day). A stationary transporter with an antenna on board will survive winds up to 65 m/s; if necessary, structure carried on the transporter can be deployed to stabilize the transporter on the ground in this survival mode.

The transporter will carry an auxiliary generator to keep all electrical systems on the antenna operational during a move. The transporter will pick up the antenna above its azimuth bearing so that the azimuth bearing and drive can be used to rotate the base of the antenna to simplify bolt hole alignment when an antenna is placed on a pad. It may be desirable to oxygenate the air in the transporter operator’s cabin so the cabin must not have large air leaks.

When an antenna is picked up a time goal of 20 min is required from the time of arrival of the transporter to the time of departure with an antenna on board. When an antenna is placed down on a pad a time goal of 30 min is required from the time of arrival of the transporter until the transporter has departed and the antenna is ready to be pointed.

4.2.15 Receiver Cabin

A receiver cabin with dimensions approximately as shown in Figure 1 of Napier et. al., 1996,
Napier et.al. 1996
will be provided at the Cassegrain focus. Temperature in the cabin will be maintained by an antenna mounted HVAC system at 16 C to an accuracy of +- 1C. The electrical power consumption of equipment in the cabin will not be less than (TBD) kw nor greater than (TBD) kw. The mass of equipment in the cabin will not be less than (TBD) kg nor greater than (TBD) kg.

A built-in mechanism will be provided so that a receiver can be lifted from the ground, through the cabin door and into its observing location, all without significant man-handling of the receiver. Part of the installation of a receiver may involve the use of a separate special purpose vehicle, such as a high fork-lift, which lifts the receiver through the cabin door.

The cabin will be watertight and a thin RF-transparent membrane will cover the aperture through which the RF beam enters the cabin. A computer actuated shutter will be deployable to protect the membrane when necessary.

It may be desirable to oxygenate the cabin air when workers are inside so the cabin must not have large air leaks.

4.2.16 Monitor and Control

The following functions on the antenna will be controllable under remote computer control:

Antenna position and scan rate

Subreflector position in x,y,z and nutation

Power distribution switching from normal to critical power and complete power down

Receiver cabin HVAC temperature set point

The following functions on the antenna will be monitored by a remote computer:

Antenna position and rate (velocity and direction)

Motor currents and all power supply voltages in the servo system

Subreflector position

Readout from any metrology devices

Readout from any temperature probes

HVAC system performance

Limit switch status

The following fault conditions will be automatically sensed and acted on at the antenna:

Power down after smoke detection

Power down after loss of a phase of the power supply

Loss of a drive motor

Drive shutdown if antenna oscillation detected

Antenna stow if command link from control building lost

4.2.17 Interfaces to Other Subsystems

The following interfaces must be defined:

Monitor and control digital interface

Interface between antenna and transporter

Interface between subreflector support legs and the subreflector support mechanism

Interface between antenna and its concrete observing pad

Interface to the electrical power system

Interface to any special cable wrap required for RF signals

Interface to the receiver package in the receiver cabin

Interface to any equipment racks in the receiver cabin

Installation procedure for receiver package

4.2.18 Maintenance and Reliability

Because of the remote site and large number of antennas the reliability and maintainability of the antennas are important. The antennas will be designed so that, with normal preventive maintenance, they should operate for 30 years without requiring elevation or azimuth bearing or reflector surface replacement. Although they should not be required, straightforward elevation and azimuth bearing replacement procedures must be included in the antenna design. All normal repair and maintenance actions should be able to be completed by a two- person crew in 4 hours. To the maximum extent possible all equipment on the antenna should be "modularized" so that a failure can be cured by simply swapping out the failed component without the need for any repair in place. Examples of equipment which should be designed for easy replacement includes gear boxes, drive motors, HVAC equipment, servo-system electronic components and the subreflector position control mechanism.

4.2.19 Manufacture and Assembly

The antenna will be designed for economic production costs.

It is expected that the first two antennas will be tested initially at a site in the US and later shipped to the MMA site so the ability to disassemble the antenna into pieces for overseas shipping is required.

The high altitude and remoteness of the MMA site make it desirable to minimize the amount of work required on the high site. It is expected that the antennas will be assembled, outfitted and tested at an Operations Support Facility 50 km from the MMA site at an altitude of 2400 m. They will be carried to the MMA site on the transporter vehicle or, in the event that this proves not to be feasible, they will be disassembled into just two pieces, the mount and the reflector, for transportation to the site on trucks. Thus the antenna should be designed for easy disassembly at the elevation axis and both the reflector and mount must have pickup points for handling as single units.

4.3. Current Design Concepts

At present, two antenna concepts are being investigated, both of which are expected to meet MMA requirements.

4.3.1 Concept A

This concept has been developed principally within NRAO and BIMA and is described in Section 4.2.3 of Lugten et.al., 1998b.
Lugten et.al., 1998b

4.3.2 Concept B

This concept has been developed principally within OVRO and is described in Woody and Lamb, 1998.
Woody and Lamb, 1998

4.4. Procurement and Construction Plans

The plan for procuring the MMA antennas is currently as follows:

(1) The MMA Antenna Working Group is developing two design concepts in order to be sure that we fully understand all of the requirements of the antenna and that these requirements are affordable within the MMA budget. Full information on MMA antenna requirements and design concepts will be given to interested companies at a workshop in September 1998 to allow the companies to begin preparing for the bid.

(2) An RFP (Request for Proposal) for the design and fabrication of the first MMA antenna will be issued at the end of 1998. The procurement will be a fixed-price contract to a performance specification. All information developed by NRAO in its studies of the concepts described in Section 3 above will be provided to prospective bidders, and bidders can propose one of the NRAO concepts or an alternative design, but in either case it will be the responsibility of the contractor to meet the performance specifications. In the RFP response the bidders will be required to describe their proposed design in some detail, to provide the cost of the design and fabrication of the first antenna and a not-to-exceed estimate for the cost of the antenna in production quantities. An option for a second copy of the antenna, to be

exercised in October 2000, will also be requested.

(3) A possibility, still under consideration, is that two parallel design contracts will be issued to two different companies, with the first antenna fabrication contract to be awarded competitively, based on predicted performance and production cost, after completion of the design phase.

(4) The first antenna will be delivered in June, 2001, and then tested extensively for 1.5 years so that there is high confidence that the design is adequate to meet the astronomical requirements.

(5) With the antenna design validated by adequate testing, the production run of the antennas can be procured on a "build-to-print" basis rather than to a performance specification. That is, NRAO can take the risk that the production antennas will meet performance requirements, thereby reducing cost and increasing the number of possible vendors who could produce antenna components. The RFP for the production run will be issued in January 2003, with a required antenna delivery of 8 antennas per year. The antennas will be fabricated in the vendor’s factory and pieces of the antenna will be accepted on the basis of mechanical acceptance tests in the factory before the pieces are shipped to the Operations Support Facility for assembly. It is not yet decided whether antenna assembly will be performed by a contractor or by NRAO. The main reason to consider having NRAO take responsibility for assembly is that in the long term NRAO must have full capability to maintain, repair and improve the antennas on the remote site and an effective way to develop this capability would be to also assemble the antennas.

4.5. Test Plans and Results

4.5.1 ON THE FIRST ANTENNA, BEFORE SECOND ANTENNA BECOMES AVAILABLE

NRAO Installation of:

- Thermistors
- Tilt meters
- Control interfaces
- Optical telescope, CCD camera

General checks:

- General mechanical inspection, wiring checks
- Mechanical operation: brakes etc.
- Interface integrity
- Mechanical slew rate check
- Mechanical tracking check
- Surface setting check (theodolite?)
- Tiltmeter checks of azimuth rotation

Antenna dynamic (mechanical) response:

- Resonant frequencies, accelerations
- Check motor currents, bearing friction, power consumption when slewing & tracking
- Weather-proof?

Monitoring:

- Start systematic monitoring of temperatures, tilt meters, motor currents, ambient conditions (wind, temperature ...)

First tracking and pointing tests:

- **Optical pointing measurements**
  - Needs CCD, interfaces, computer + software
  - Needs simple interface to telescope drive system (computer?)
- Simple servo tests:
  - Move to star, slew away, slew back:
  - Servo response, oscillation?
- Tracking tests:
  - Track edge of moon, stars ...
- Optical Pointing checks
  - Measure pointing offsets on > mag 5 stars
  - First astronomical pointing model
  - Consistency of pointing (night to night, temperature, wind ...)

Electromagnetic measurements:

- Prime Focus Holography.
  Initial Requirements:
  - Requires pointing and tracking understood,
  - Control system interface,
  - Holographic system, frontend and backend, tested out.
  - Holographic reference feed measured
  - Integrated holographic data acquisition, telescope pointing
  - Observing modes tried and tested
  - Holography data analysis system available
- Terrestrial holographic measurements
  - Beacon on nearby mountain (90 GHz?)
  - Repeat until no longer useful:
    First holography maps: 129*129, 10-cm resolution
    Repeat, check for repeatability
    ADJUST SURFACE.
    Derive efficiency
    End repeat
- IF POSSIBLE:
  - Deformations as function of elevation.

- **Using 90 GHz/230 GHz, secondary focus receiver**
  - Needs nutating subreflector
  - Measure radio pointing (mainly planets).

- Reconcile radio/optical pointing
- Derive radio pointing model. Check for consistency, stability.
- Check radiotracking (edge of moon, edge of Jupiter)
- Measure efficiency at 230 GHz:
  Radiometrically, planet
- Measure error pattern (e.g. sensitive beam map on planet, moon scan).
- Measure forward and rear spillover, variation with elevation? (Hot/cold calibration, sky tips)
- Reconcile holographic measurements with radiometric, efficiencies and error pattern measurements
- Using 230 GHz measurements, confirm fast switching characteristics
- Surface deformation with elevation:
  Problem. Error pattern? Beam shape?
  (Satellite availability?)

- Reproducibility after transportation
  Tilt meters? New pointing determination needed?
- Confirm that solar observations are possible
  (Heating, panel IR scattering, pointing)
- Subreflector.
  - Is a nutating subreflector needed?
  - Compare point source measurements, OTF maps, with and without nutating S/R.
- Spectral purity:
  - Stability of baselines,
  - Standing waves.
    (Requires spectrometer.)

4.5.2 WITH SECOND ANTENNA: INTERFEROMETER TESTS

- Are we SURE about close packing limitations?
- Phase stability (lateral displacements, wind, bearing slop)
- Phase stability while fast switching? (Structure oscillations?)
- More extensive radio pointing tests now possible
- **Interferometric Holography:**
  - Using 86 GHz SiO maser (needs spectral correlator) and/or planets.
  - Needs complete interferometric, phase stable, fringe tracking, delay tracking electronics.
  - Measure surface (e.g. 48*48) deformations as function of elevation.
- General correlations:
  - Use archived weather (wind, temperature, gradients ...) data to look for correlated effects on antenna (surface deformation, pointing ...)

4.6. Acknowledgments

This chapter represents the work of the MMA Antenna Working Group: J. Bieging, J. Cheng, D. Emerson, M. Fleming, M. Holdaway, J. Kingsley, J. Lamb, J. Lugten, J. Mangum, J. Payne, J. Welch, D. Woody

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