THE LARGE MILLIMETER TELESCOPE

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ABSTRACT

The Large Millimeter Telescope is a 50m-diameter, millimeter-wave telescope that is being built in the country of Mexico by the Instituto Nacional de Astrofísica, Óptica, y Electrónica and the University of Massachusetts at Amherst. In this paper, an overview of the project is presented, with emphasis on the expected use of metrology and active control systems to reach the antenna's performance objectives.

INTRODUCTION

The Large Millimeter Telescope (LMT) is a joint project of the University of Massachusetts (UMass) in the USA and the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE) in Mexico to build the world's largest filled-aperture radio telescope for use at short millimeter wavelengths. Specifically, the LMT will have a diameter of 50 m and will operate with good efficiency at wavelengths as short as 1 mm. The construction of the antenna is now well underway (see Figure 1), and it is expected to be completed in 2004.

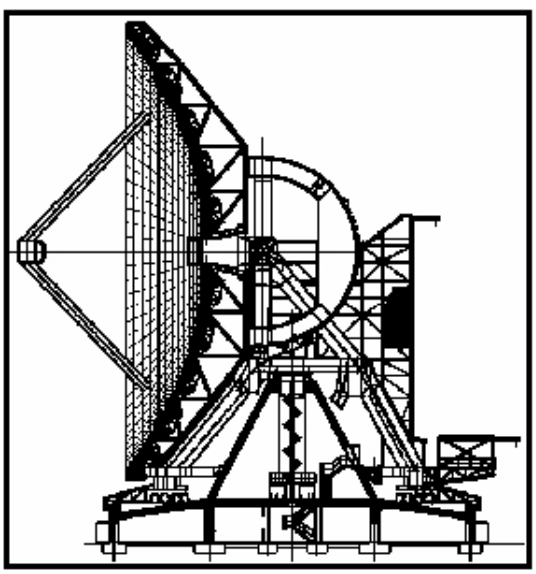

Figure 1: (Left) Overview line drawing of LMT. (Right) Present status of construction at site (April 2002). Photo shows concrete foundation and initial layout of lowermost section of the alidade for the antenna. Diameter of track on foundation is 40m; length of alidade beams shown is 27.6m.

The LMT is being built at an altitude of 4600 m atop Volcan Sierra Negra, an extinct volcanic peak in the state of Puebla, Mexico, approximately 100 km east of the city of Puebla. This location was selected following radiometric tests at a number of potential mountain top sites in Mexico. The 19 degree latitude was a significant factor in the site selection, and the LMT's coverage of the southern sky will be very good, with the Galactic center culminating at an elevation of about 45 degrees. The atmospheric opacity, as measured by a 225 GHz tipping radiometer, is low, with a median value of 0.1 nepers during approximately 9 months of the year (corresponding to about 2 mm of precipitable water vapor). The meteorological conditions at the site are

relatively mild for such a high altitude. For antenna performance, the most critical factor is the wind speed, since the wind distorts the surface of the dish and affects the antenna pointing. The median wind speed is only 5 m/s, and the telescope has been designed with the goal of meeting its specifications in winds up to 10 m/s. These conditions are met approximately 90% of the time. Snow fall is generally light during the year, and the diurnal temperature cycle is typically only 5K.

SPECIFICATIONS

The major LMT performance metrics are summarized in Table 1. These requirements are ambitious, and the LMT concept has been under development for over ten years. This development has culminated in a final detailed system design, produced by MAN Technologie [1]. The LMT will be an "open-air" telescope with no radome or astrodome enclosure to obstruct its view. This configuration gives the optimum performance under the best observing conditions, particularly for measurements with sensitive, broadband continuum systems. However, since the telescope is exposed to the wind and solar insolation directly, the telescope performance will degrade in some meteorological conditions and care must be taken to mitigate these effects. The LMT approach is to create an "active" telescope which measures properties of the telescope in real time and uses the predictions of finite element models of the structure to improve its performance.

Table 1: Principal LMT Performance Specifications

Parameter	**Specification**	
Diameter	50m (1963 m^2)	
Surface Accuracy	75μm rms (*Goal:* 70 μm)	
Pointing Accuracy[1]	1.0" rms (*Goal:* 0.6")	
Predicted Performance:	**λ3.0mm**	**λ1.2mm**
Aperture Efficiency	0.65 (*Goal:* 0.70)	0.40 (*Goal:* 0.45)
Sensitivity	2.2 Jy/K (*Goal:* 2.0 Jy/K)	3.5 Jy/K (*Goal:* 3.1 Jy/K)
Beam Size (FWHM)	15"	6"

Notes:
[1]: after pointing calibration; within time period of two hours; within 10 degrees of pointing calibrator.

TECHNICAL APPROACH

Meeting the above specifications requires a significant step forward in antenna design. Two specifications are particularly important to the astronomical use of the telescope: (1) the surface accuracy; and (2) the antenna pointing accuracy. The adopted strategy to meet each of these goals is to supplement conventional antenna designs with various "active" systems to bring the final performance within the requirements. Initially, the LMT will operate primarily in an "open loop" manner with active systems used to correct various effects that have been quantified with calibration observations. It is important to note that under the initial, "open loop," approaches discussed below, the LMT is predicted to reach its performance goals under benign thermal conditions and low wind loads. Happily, these conditions exist for a large fraction of the time at the Sierra Negra site. Eventually, however, it is hoped that real time metrology will play a role in commanding the active systems in a "closed loop" scheme that will extend the time available for observations at full performance.

Surface Accuracy

The easier of the LMT's two main challenges is the surface accuracy. The LMT approach relies on an active surface which includes 180 moveable surface segments. Each segment consists of a surface panel of CFRP (carbon-fiber-reinforced plastic) supported by a very stiff reaction structure, which is attached to the reflector backstructure by a space frame. Four actuators can adjust each space frame in relation to the backstructure.

Current best practices for maintaining surface accuracy will be employed, including thermal monitoring and management and surface setting based on holographic measurements.

One of the features of the "active surface" approach is that, while many existing antennas have estimated their thermal and gravitationally-induced errors, the LMT will have the means to actually correct these errors. Initially, the active surface will be controlled in an "open loop" strategy with a look-up table of surface corrections for different elevation angles and temperature patterns. The general behavior of the surface under gravity, thermal, and wind loads, may be predicted from models of the structure. However, the detailed behavior, which is required in order to implement this strategy, cannot be predicted with sufficient precision to build the look-up table, and careful measurements of the surface deformation must be made in order to achieve the final specifications. Thus, commissioning measurements to calibrate the active surface positions will be an essential part of the initial work at the telescope.

Simulations by MAN Technologie indicate that the LMT should be able to maintain surface accuracy even in the presence of significant (6-10 m/s) winds. The main area of concern in high wind conditions is the location of the secondary with respect to the primary, since high winds in certain directions can cause a defocus of the antenna. The solution to this problem is measurement of the distance to the secondary with respect to the primary. Thus, an important next step in the use of metrology at the LMT will be the sensing this range. Preliminary studies of this measurement suggest that the LMT requirements are close to being realizable with present laser ranging systems.

Pointing Accuracy

The LMT pointing accuracy requirement is considerably more challenging than its surface accuracy requirement. Under benign conditions, with no wind load and stable nighttime temperatures, the antenna designer predicts that the structure is capable of satisfying the basic pointing requirements. However, wind and thermal loads introduce significant pointing errors which must be sensed and compensated. Here, again, the LMT strategy is to start with current best practice and build on it through the addition of appropriate active systems.

The initial system will rely on standard techniques, such as the use of an antenna pointing model, thermal stabilization of the structure, and careful attention to the design of the antenna motion controllers. These basic principles will be supplemented by measurements to characterize the behavior of the structure, including inclinometers mounted near the telescope elevation axis and temperature sensors on the structure, which may be used with finite element models to determine structural deformations and predict pointing behavior. Once again, only the general pointing behavior of the antenna can be predicted by the structural models, and correcting for its detailed behavior requires actual measurements and calibration.

The best strategy for pointing corrections is to actually measure structural deformations, such as the shape of the primary and the location of the subreflector with respect to the best fit parabola, and use this information to improve the antenna pointing. An initial concept for such a system was developed in collaboration with MIT Lincoln Labs and included both laboratory demonstration and characterization. The basic principle was to use a system of laser sensors to sense the motion of several points on the primary surface in the "z-direction" parallel to the telescope optical axis with respect to a central reference structure located near the vertex of the parabola. Such measurements could constrain the location of the parabola with respect to the central structure. A multi-axis laser ranging system would then be used to locate the secondary with respect to this same structure and thus to the primary. Calibration of the mount pointing, with an optical telescope attached to the central structure, could then relate the mirror positions to the celestial sphere.

CONCLUSION

The LMT presents many interesting technical challenges which must be overcome to meet its basic requirements. The project is approaching these challenges in a series of steps. The initial step involves measuring and calibrating the behavior of the basic structure, with its active surface, in order to operate in an open loop manner. In this phase, the system is expected meet its basic performance requirements under most environmental conditions and only suffer degraded performance under high winds. To improve upon this situation will require development of metrology systems to measure the shape of the primary and the location of the secondary with respect to it.

With nearly 2000 m^2 of collecting area and an excellent surface accuracy, the LMT's sensitivity will

exceed that of existing millimeter-wavelength telescopes by a wide margin. This basic sensitivity is enhanced, for continuum observations, by the single dish's ability to make use of incoherent detectors. Moreover, as a completely filled aperture, the LMT will have the optimum sensitivity to low surface brightness emission at an angular resolution of 6-12 arcsec, which is comparable to that of the maps presently made with interferometric arrays. Consequently, we expect the LMT to take a valuable place in the world's complement of millimeter-wave facilities.

ACKNOWLEDGEMENTS

The authors are pleased to acknowledge that the excellent design and technical approach for LMT has been developed by Hans Kaercher and the group at MAN Technologie under contracts with INAOE and UMass.

The LMT/GTM project is a major undertaking and it is supported by a number of agencies in Mexico and the United States. In Mexico, we gratefully acknowledge the support of the Instituto Nacional de Astrofisica, Optica, y Electronica (INAOE) and by the Consejo Nacional de Ciencia y Tecnologia (CONACyT). The effort in the Unites States is supported by funding from the Commonwealth of Massachusetts and the Advanced Research Project Agency, Sensor Technology Office DARPA Order No. C134 Program Code No. 63226E Issued by DARPA/CMO under contract #MDA972-95-C-0004. Funding for LMT instrumentation is also supported by National Science Foundation grants AST 0100793 and AST 0096854.

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