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**HOLOGRAPHIC SURFACE QUALITY MEASUREMENTS OF  
THE SUBMILLIMETER ARRAY ANTENNAS**

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**ABSTRACT**

The surface smoothness specification for the 6-m diameter antennas of the Submillimeter Array (SMA) is  $12\ \mu\text{m}$ , due to its short operating wavelengths down to  $\sim 330\ \mu\text{m}$  ( $\sim 900\ \text{GHz}$ ). We describe near-field holographic measurements at 232.4 GHz to map and set the surface to achieve this goal. The surfaces of 5 antennas have been adjusted to within  $\sim 20\ \mu\text{m}$  rms so far. The panels on one of the antennas have been set to reach a smoothness of  $13\ \mu\text{m}$  rms. Long term monitoring tests show a repeatability of  $11\ \mu\text{m}$  rms over 7 months, during which the antenna was transported between pads. The stability of the surface indicates that it will be possible to efficiently operate the SMA, unaffected by Array reconfigurations over long periods.

**INTRODUCTION**

The Submillimeter Array which recently became partially operational on Mauna Kea is a reconfigurable array of 8 antennas, each of 6-m diameter (Figure 1) [1]. It will carry out synthesis imaging of celestial objects over the wavelength range  $\sim 330 - 1700\ \mu\text{m}$  ( $\sim 180-900\ \text{GHz}$ ). For efficient short wavelength operation, it is necessary that the surfaces of the antennas be measured and set to a high accuracy. The SMA specifications require a surface accuracy of  $12\ \mu\text{m}$  rms. In this presentation we describe our approach to achieving this goal and the results.



Figure 1: A view of the SMA on Mauna Kea. The Array will have 8 antennas when completed.

**STRATEGY**

We use a combination of terrestrial and celestial holographic measurements to study the antenna surface. Terrestrial holography using a ground-based signal source can provide high signal to noise ratio. This is our primary method of measuring the figure of the antennas at a resolution of  $\sim 10\ \text{cm}$  across the surface of the dish, at a fixed elevation. The

surface error maps generated are used to study and correct panel-panel errors and panel flexing. Celestial holography with coarser resolution, using planets as signal sources, allows us to study gravitational deformation of the dishes with elevation.

## MEASUREMENT SYSTEM

We have set up two low-power ( $\sim 1$  nW) signal sources that emit phase-locked tones at 232.4 GHz and 682.5 GHz for holographic measurements and other general tests of the Array (Figure 2). These are mounted on the Subaru Telescope building, at a distance of  $\sim 200$ -m from the central ring region of the Array, in the near-field for the SMA antennas and at an elevation of  $\sim 19$  degrees (Figure 3a). The holography system uses the standard SMA optics, receivers and IF



Figure 2: Test signal sources emitting phase-locked tones at 232.4 & 682.5 GHz, mounted on the cat-walk of the Subaru Telescope.

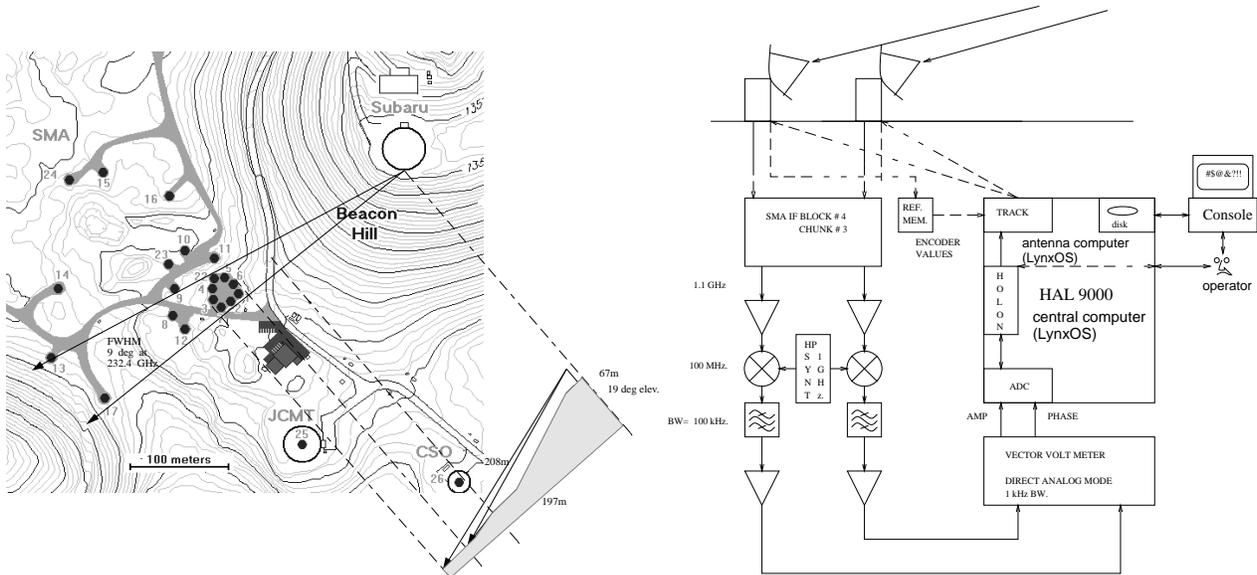


Figure 3: (a) The geometry for SMA near-field holography (b) The holography system block diagram.

electronics. Currently, a vector voltmeter is used as the back-end to measure the complex beam pattern of the antenna under test. A block diagram of this system is shown in Figure 3b. A second antenna of the Array provides the phase

Antenna#4\_Before\_rms:60u

Antenna#4\_After\_rms:15u

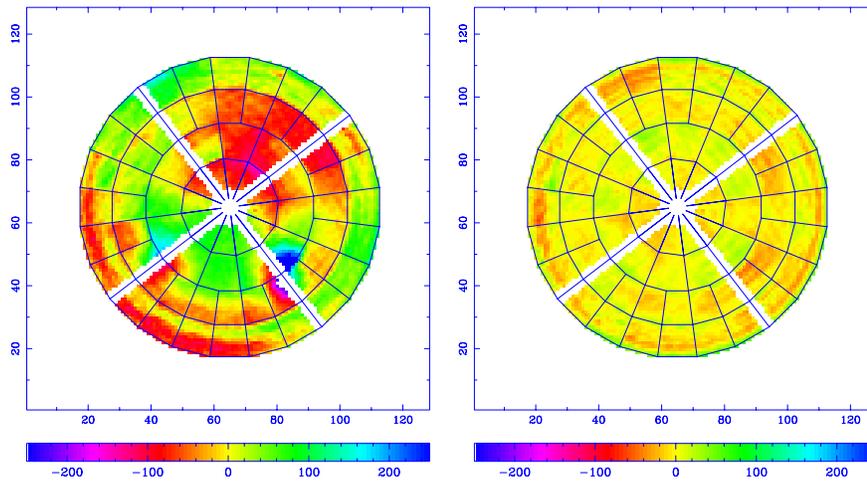


Figure 4: Left panel shows the surface error map when the antenna was first deployed, with an rms of  $\sim 60 \mu\text{m}$ . After 3 rounds of adjustment it was improved to  $15 \mu\text{m}$  as shown on the right panel. The grey scale units are microns.

reference. We will eventually switch over to using the Array correlator as the back-end. The measurements are made on-the-fly, typically mapping a  $96 \times 96$  raster with an elevation spacing of  $33''$  at  $232.4 \text{ GHz}$ , with the subreflector refocused for the near-field.

The data is re-sampled off-line onto a regular grid, Fourier inverted and corrected for the near-field phase profile to produce the aperture phase distribution. After fitting DC, gradient and defocus errors, the phase residuals are converted to surface deviations which are used to adjust the panels. The data analysis uses an enhanced version of a software package originally developed by Zhang [2]. Four maps, made with the subreflector positioned an eighth of a wavelength apart, are averaged to overcome the effects of multiple reflections. A correction for the diffraction due to the finite-sized subreflector is also applied [3]. A complete set of measurements takes about 2 hours.

Antenna#4\_After\_rms:15u

Antenna#4\_Repeatability\_rms:8u

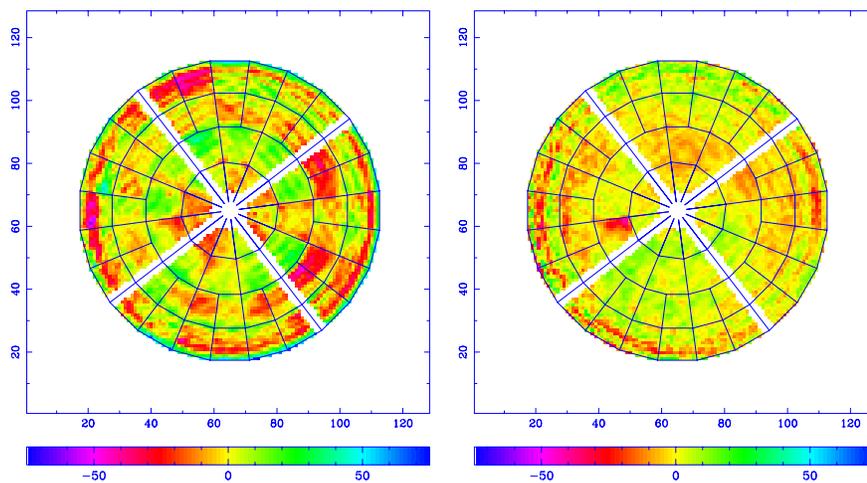


Figure 5: Short term repeatability for Ant 4. Left panel shows the surface error map and the right panel shows the difference of two maps taken 1 month apart, with a repeatability rms of  $8 \mu\text{m}$ . The grey scale units are microns.

Dec00\_ant#4\_rms:13u

Jun-Jul01\_ant#4\_rms:15u

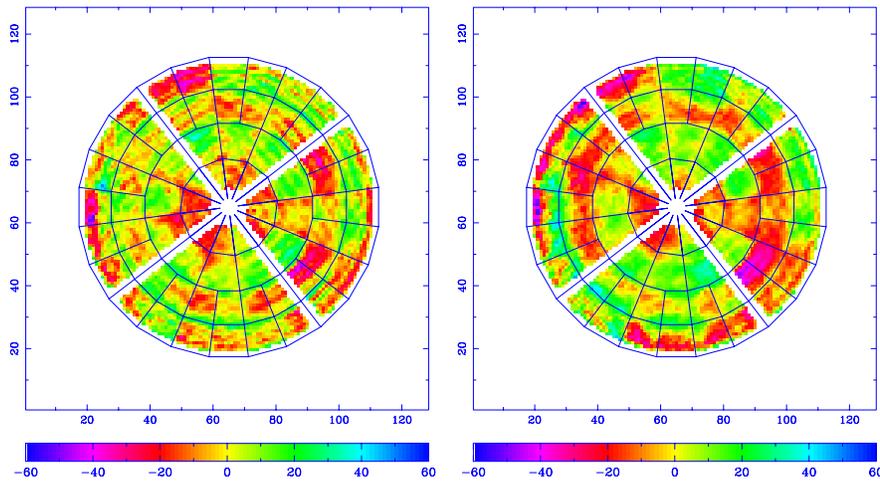


Figure 6: Long term surface stability for Ant 4. The two surface error maps were made 7 months apart. The antenna was moved from one pad to another during this interval. The average surface rms over this period is  $13 \mu\text{m}$  and the end to end repeatability is  $11 \mu\text{m}$ . The grey scale units are microns.

## RESULTS

So far the surfaces of 4 of the SMA antennas on Mauna Kea have been set to better than  $\sim 20 \mu\text{m}$  rms accuracy. The surface of one antenna (No. 4) has been set to  $13 \mu\text{m}$  rms and is under long-term monitoring tests. Typically 3 rounds of adjustments are needed to achieve  $\sim 15 \mu\text{m}$  rms starting from  $\sim 60 \mu\text{m}$  (Figure 4). The short-term repeatability of the measurements is  $8 \mu\text{m}$  rms and the repeatability over several months is  $11 \mu\text{m}$  rms (Figure 5, 6). This dish is among the best existing radio reflectors in terms of the ratio of surface smoothness to diameter. During the test period, the antenna was transported from one station to another without ill effect. This implies that array reconfigurations will not affect surface accuracy. The current maps of our best antenna show significant repeatable panel-panel errors suggesting the potential for further improvements. Holography at  $682.5 \text{ GHz}$  is also being attempted [4], which will further reduce

0206\_0749\_a5.amp

0206\_0749\_a5.phase

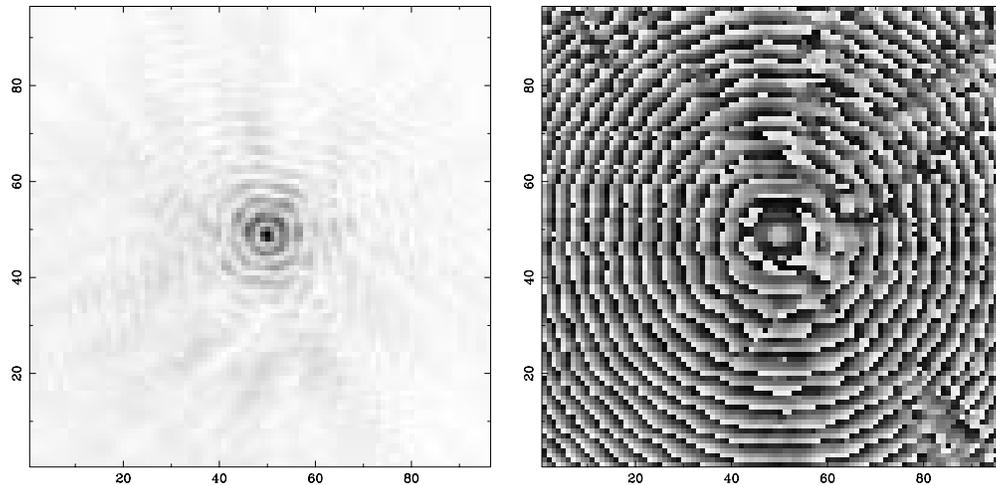


Figure 7: Beam domain amplitude and phase at  $682.5 \text{ GHz}$  obtained by raster scanning a  $96 \times 96$  point grid, spaced  $11''$  and centered on the signal source.

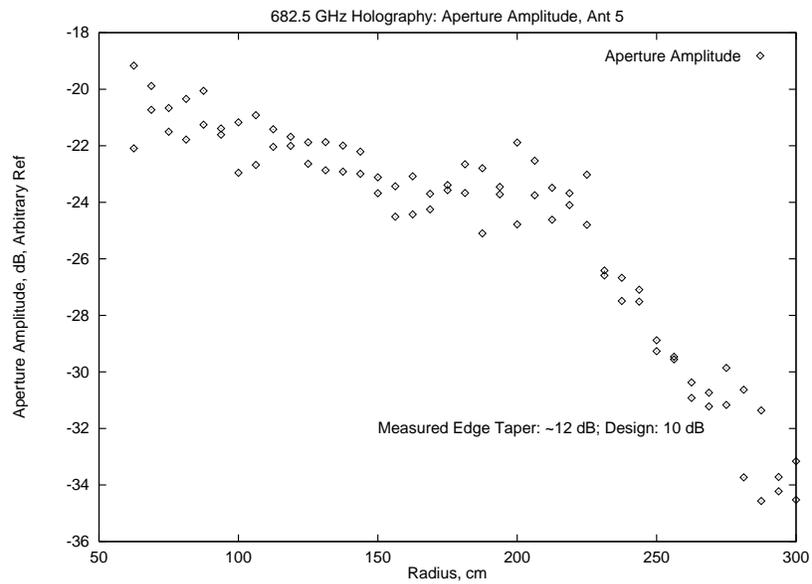


Figure 8: Measured radial illumination pattern for antenna 5. The aperture domain amplitudes were averaged in azimuth to produce this plot.

the effects of diffraction due to the subreflector and permit the accurate characterization of the high-frequency systems. Preliminary results from this experiment are presented in Figures 7 & 8 which show the beam domain measurements and the aperture domain illumination pattern derived.

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### REFERENCES

- [1] J. M. Moran, "Submillimeter array", in *Advanced Technology MMW, Radio, and Terahertz Telescopes*, Ed. T. G. Phillips, Proc. SPIE Vol. 3357, p. 208-219, 1998.
- [2] X. Zhang, "Holis", *SMA Technical Memorandum 116*, 1997.
- [3] R. Hills, FORTRAN diffraction code, unpublished.
- [4] T. K. Sridharan, C. E. Tong, M. Saito, N. Patel, R. Blundell, "A Holographic Measurement System for the SMA Antennas at 680 GHz", in *Proc. 13th Space THz Tech. Symp.*, Cambridge, MA (March 2002)