Design and Performance of the New 10 m Antenna for the Nobeyama Millimeter Array

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1. Introduction

The Nobeyama Millimeter Array (NMA) consists of six 10 m antennas located at Nobeyama Radio Observatory 150 km west of Tokyo at an elevation of 1350 m. The current NMA observing frequency bands are 100 GHz, 150 GHz and 230 GHz. Originally constructed as an aperture synthesis interferometer with five 10 m antennas, NMA has been recently expanded to six antennas by adding a new 10 m antenna[1]. New developments and experimental items were incorporated in the new antenna to reflect the results to the telescope design for the future.

The new and old 10 m antennas are shown in Figure 1. One of the new developments is the new design to achieve higher efficiency than old antennas. A shaping optics has been adopted for beam−waveguide reflectors instead of main and sub reflectors and a nearly uniform aperture illumination has been achieved. In this paper, we report the design and the measured performance by radio holographic metrology.

2. Shaped Beam−waveguide Design

Figure 2 shows the antenna configuration. The #2 and #3 mirrors are shaped so that they provide a uniform aperture illumination in order to obtain high aperture efficiency. To simplify the actual design procedure, the main reflector, sub reflector (Focus F_2) and mirror #1 were replaced with an equivalent paraboloid[2]. Point O is the phase center of incident wave on mirror #3. Radiation pattern incident on mirror #3 from mirror #4 via horn, #11, #10 and #5 mirrors is calculated by beam mode expansion method[2]. The reflector shaping method we used is based on reference[3]. Reflector is shaped from an initial quadratic reflector using reflector shaping functions. For mirror #3, the initial quadratic reflector is hyperboloid with foci O and F_1. As for mirror #4, the initial quadratic reflector is ellipsoid with foci F_1 and F_2'. F_2 and F_2' are symmetrical with respect to mirror #1. When mirror #3 is shaped from the initial quadratic reflector using reflector shaping functions, configuration of mirror #2 is determined so that the ray from O is reflected by the #3 and #2 mirrors, and focused at F_2' by using geometrical optics.

The optics is designed to be efficient at 100−200 GHz. To reduce blockage, sub reflector size is minimized (40cm) and the foot positions of the quadrupod are shifted to the edge of main reflector. Main reflector is consisted of 36 high surface accuracy panels with a motorized adjusting system.

The calculated aperture distribution is shown Figure 2 and the calculated antenna gain budgets is shown in Table 1.

3. Radio Holographic Measurement

We have made radio holographic measurements to investigate the surface accuracy and the electrical performance of the new 10 m antenna. With the radio holographic measurement, we can get a complex field distribution of the antenna aperture by two–dimensional Fourier transform of the complex far–field pattern of the antenna. The measured amplitude and phase distributions correspond to the illumination and surface error distributions. We used another 10 m antenna as a reference which is located at the nearest distance at 20 m from the antenna under test. The small separation between the antennas is very important to decrease the effect from atmospheric phase fluctuations that degrade the accuracy of the measurement. Sensitive SIS receivers enable us to measure the field distribution of the antenna with signal to noise ratio of about 30 dB. We measured a complex far–field pattern at 64 x 64 points covering 1 deg x 1 deg area for about one hour. The achieved spatial resolution of the measurement was 18.5 cm and therefore there are typically 25–30 mesh points on each panel with a typical size 1 x 2 m.

The measurement was made during 23 January and 9–13 February 1996. Before evaluating the surface error, we applied a best fit panel model[4] to each panel of the telescope and adjusted the panel to reduce the surface error. Because the signal was located in the near field region and the new antenna could not completely be focused to it, the near field and the defocus corrections were applied before getting the surface error. After several iterations of measurements and adjustments the surface error of the new antenna was improved from 125 micron to 45 micron rms. Figure 4 shows one–dimensional illumination pattern versus radius after panel adjustment.

4. Summary

The obtained aperture distribution (Figure 4) was consistent with that expected from the design (Figure 2). Smaller values correspond to the blockage area. There is a dip at 0.4 normalized radius. This dip would be resulted from a diffraction effect at the edge of the sub reflector.

The aperture efficiency will be confirmed by a radiometric mesurement using celestial radio sources.

We conclude that the shaped beam–waveguide design provides a cost effective approach to obtain higher antenna efficiency without modifying main and sub reflectors.

References

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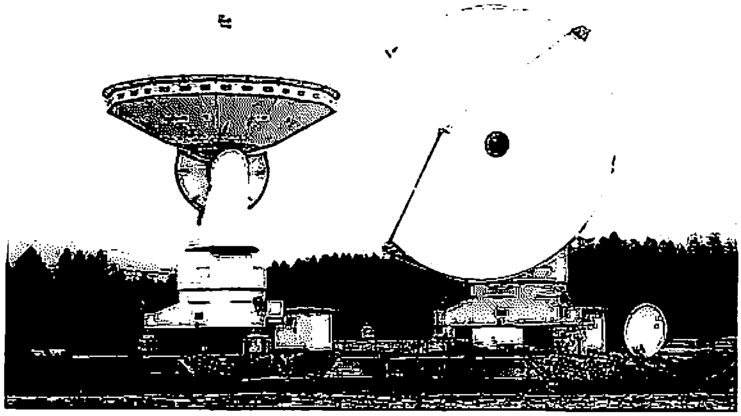

Figure 1. New 10m antenna (right) and old 10m antenna (left)

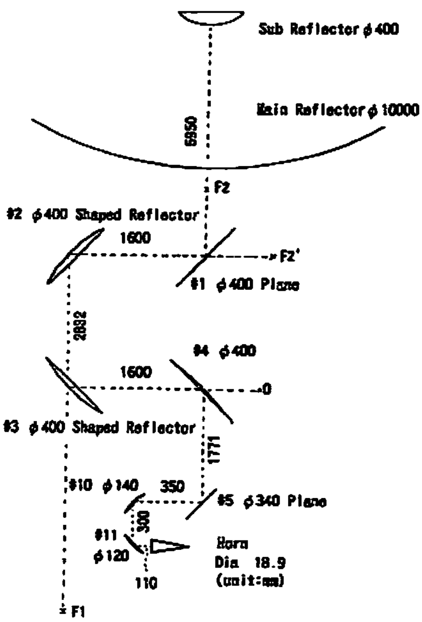

Figure 2. Antenna configuration

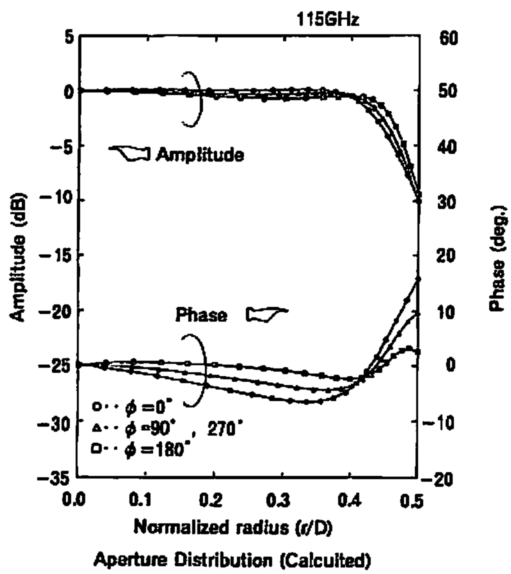

Figure 3. Aperture distribution (Calculated)

Table 1 Calculated antenna gain budgets

Item	115GHz	230 GHz	Remarks
Gain for 100% efficiency	81.62 dBi	87.64 dBi	Diameter : 10 meter
Illumination efficiency	-0.27 dB	-0.54 dB	
Blockage	-0.20 dB	-0.20 dB	Including sub reflector and support
Spillover Main Reflector Sub Reflector Beam waveguide	 -0.03 dB -0.30 dB -0.03 dB	 -0.03 dB -0.30 dB -0.03 dB	
Surface Accuracy Main Reflector Sub Reflector Beam waveguide Reflectors	 -0.16 dB neg. -0.02 dB	 -0.65 dB -0.02 dB -0.07 dB	 40 μmm RMS 7 μmm RMS (measured) 3~7 μmm RMS (measured)×7
Total Loss	-1.01 dB	-1.84 dB	
Gain at the aperture	80.61 dBi	85.80 dBi	
Aperture efficiency	79.3 %	65.5 %	

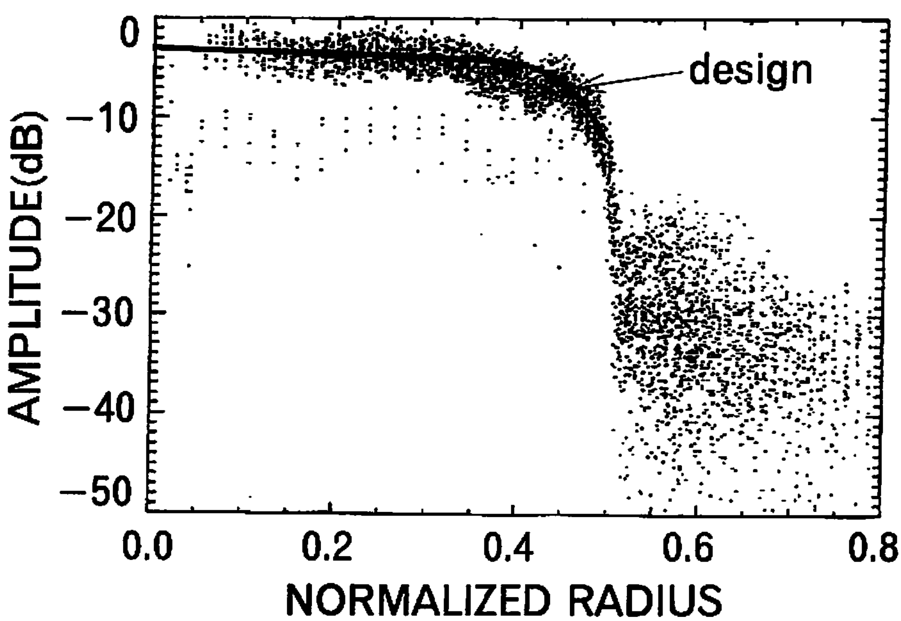

Figure 4. One-dimensional ilumination pattern
(Radio holographic measurement)