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Radio Holographic Metrology with Best-Fit Panel Model of the Nobeyama 45-m Telescope

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1 Introduction

For achieving/improving performance of radio telescopes, surface measurement with a radio holographic metrology has received increasing interests [1]. This method is faster and more accurate than classical methods using a theodolite, especially for large radio telescopes [2]. The first holography measurements of the 45-m telescope were made in 1985, using geostationary satellite signals [3]. Most of the measurements had a spatail resolution of 86 cm, comparable to the size of individual panel, typically 1.2 m × 2.2 m, and panel adjustments were mainly concerned with a global error pattern. The panel adjustments successfully improved the surface accuracy from 204 μm rms to 125 μm rms. For further improvements we need distinguish panel setting errors from manufacturing errors of individual panel.

In this paper, we applied a best-fit panel model to estimate a mean displacement and tilts for each panel. We obtained data with a higher spatial resolution(44 cm) to resolve individual panel. It was found in 1989 that the level difference of adjoining panels was about 100 μm rms and was a major source of the surface error. Panel adjustments using the best-fit panel model successfully improved the surface accuracy to 94 μm rms in 1990 and 84 μm rms in 1991.

2 Best-fit panel model

In radio holographic metrology with the best-fit panel model, a best-fit plane with minimum deviation from the phase error data is detemined for each panel on the antenna aperture, as shown in Figure 1. The setting errors and the manufacturing errors of each panel are estimated by the best-fit plane. The best-fit plane for panel i is represented by:

$$Q_i = a_i X + b_i Y + c_i \qquad (i = 1, 2, \cdots, N) \tag{1}$$

where (X, Y) is coordinates on the antenna aperture and N is total number of panels. The coefficients a_i, b_i and c_i are determined by the least squares method as follows:

$$\frac{\partial \epsilon_i}{\partial a_i} = 0, \quad \frac{\partial \epsilon_i}{\partial b_i} = 0, \quad \frac{\partial \epsilon_i}{\partial c_i} = 0 \qquad (i = 1, 2, \cdots, N) \tag{2}$$

with

$$\epsilon_i = \sum_{j=1}^{M_i} [p_{i,j} - q_{i,j}]^2 \tag{3}$$

$$q_{i,j} = a_i X_{i,j} + b_i Y_{i,j} + c_i \qquad (j = 1, 2, \cdots, M_i) \tag{4}$$

where $p_{i,j}$ is measured phase error data, $q_{i,j}$ is phase error of the best-fit plane, M_i is the total number of sampling points on panel i, and $(X_{i,j}, Y_{i,j})$ is coordinates of a sampling point. These parameters are used to derive a level difference of four adjoining panels and an average offset at panel actuators. For a reliability test, we made measurements with two panels displaced by +1.0 mm and -0.5 mm. The model underestimates the level difference and offset by factor of 0.8 [4].

3 Experimental results

We used the holography system(see Figure 2) developed by Ishiguro et al. [3]. A beacon signal of a geostationary satellite, CS-3, at 19.45 GHz was observed as a far-field point source. The satellite was at an elevation angle of 48 degree. A dual-channel FET receiver and a reference antenna of 45 cm were mounted at the prime focus.

We measured complex antenna pattern at 128×128 points which covers a 2° ×2° area. We therefore obtained a spatial resolution of 44 cm, which gives about 10-15 mesh points on a panel. Figure 3 shows the surface profile contour maps before level difference adjustments. The surface error was 138 μm rms. The level difference of adjoining panels was estimated to be 100 μm rms.

By using the best-fit panel model, we made panel adjustments. Global errors were adjusted with the remotly controled adjuster motors(Fig. 2). Since the four corners of adjoining four panels are supported by a single motorized support, the level differences can not be decreased by the adjuster motors. The level differences were thus manually adjusted. The final setting of the panels was achieved in iterative steps with intermediate measurements. We reduced the level difference to 32 μm rms in 1990, and achieved the surface accuracy of 94 μm rms(see Figure 4). Repeatability of the measurements was 40 μm rms. Figure 5 shows a comparison of the level difference in 1989 and those in 1990. Reapeatability of the level difference was 20 μm rms.

References

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[4] H.Deguchi et al., "Optimization of the surface error models in radio holographic metrology," 1990 Autumn Nat. Conv. Rsc. IEICE, B-113 (1990).

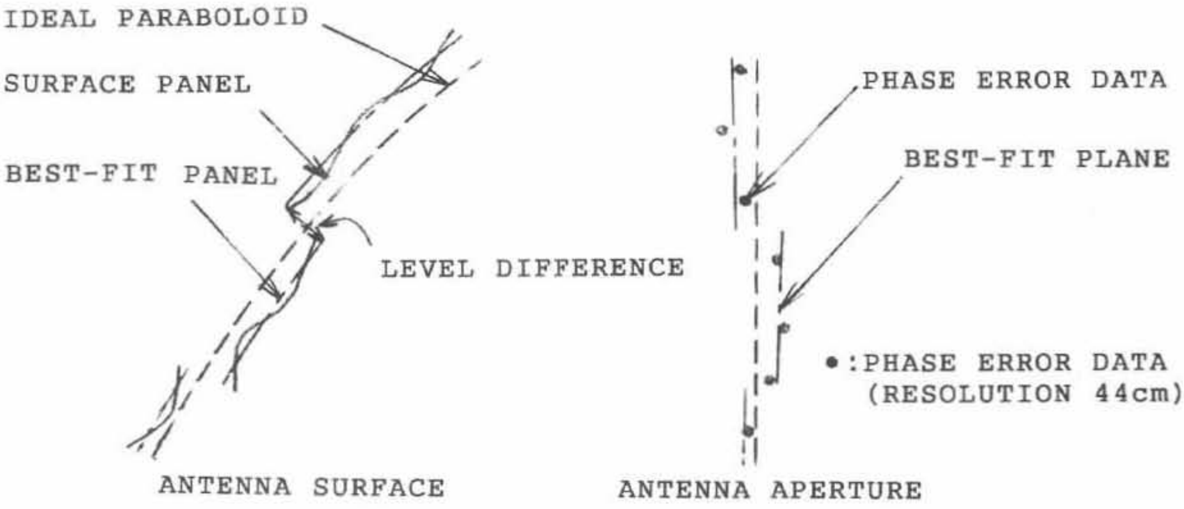


Figure 1. Best-fit panel model

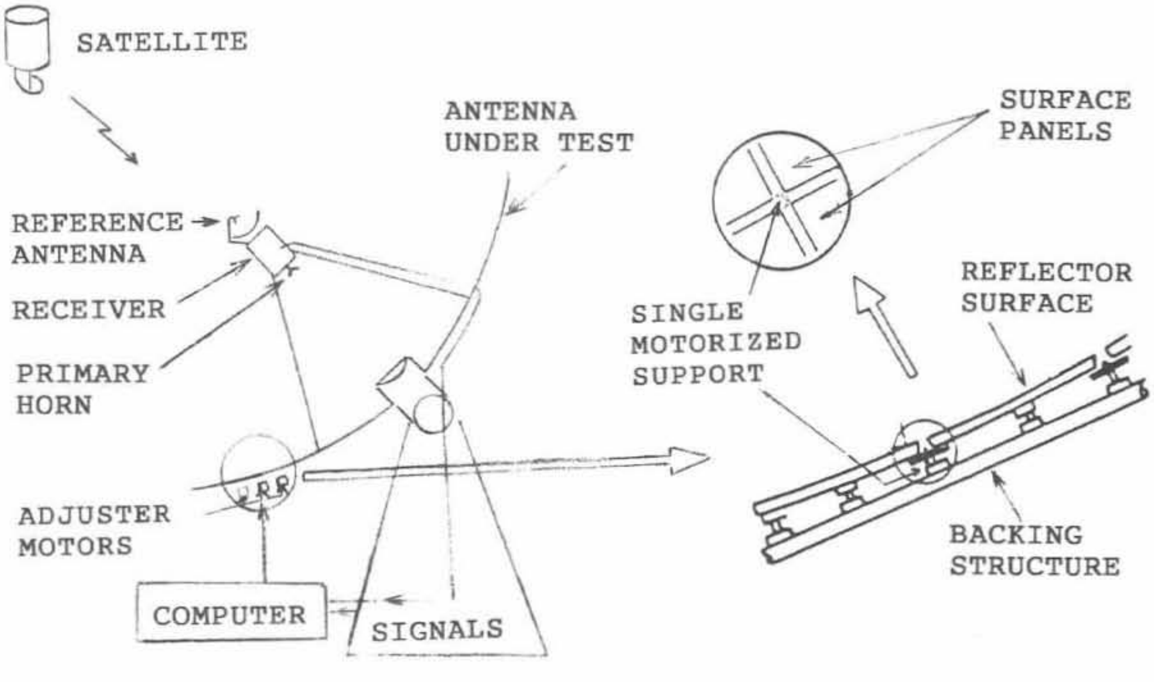
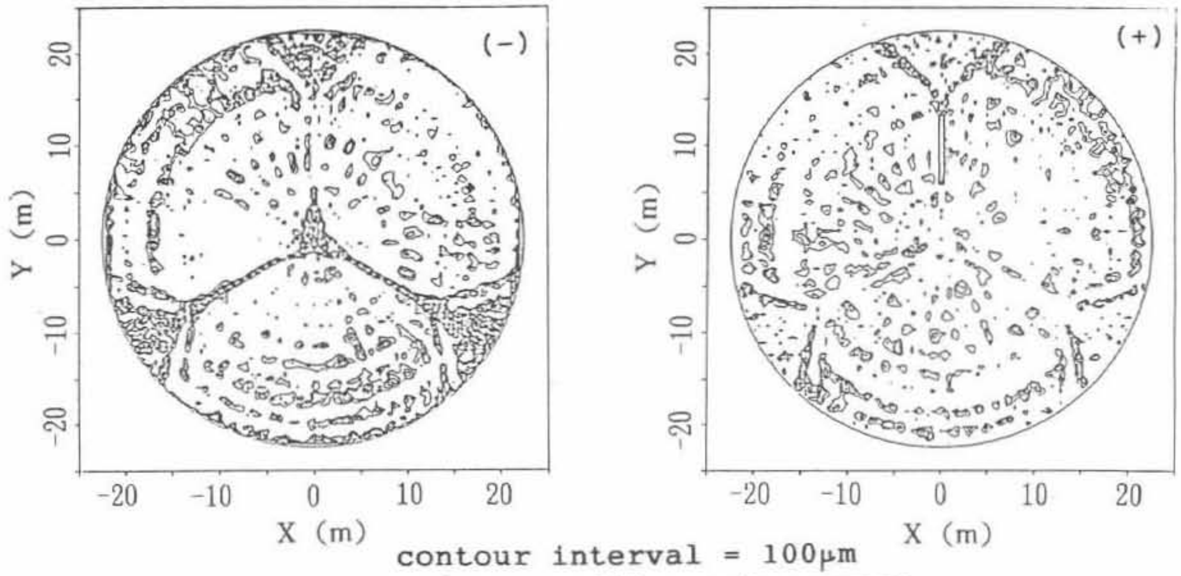
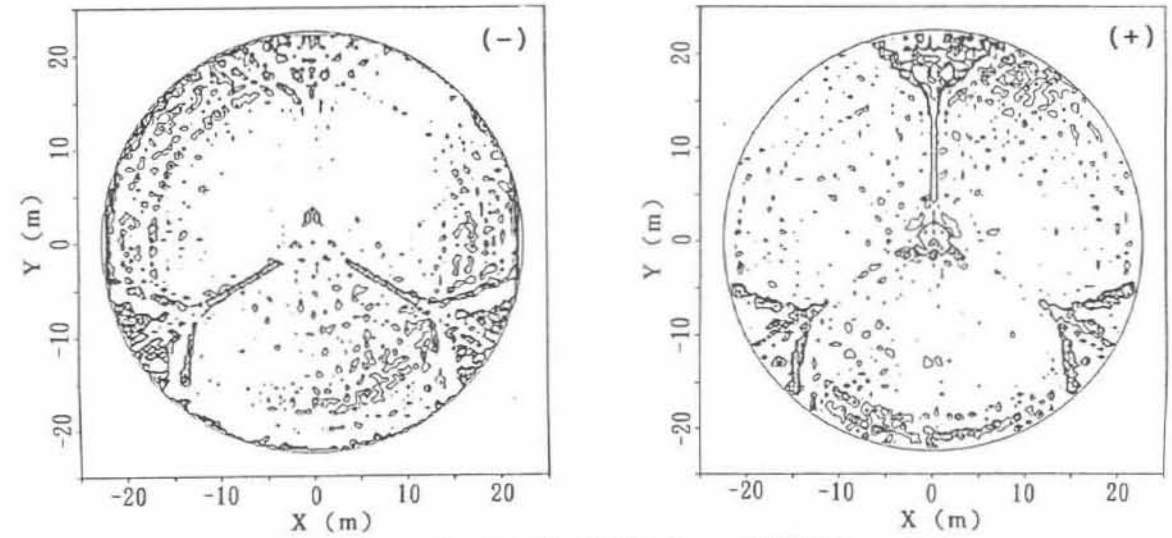


Figure 2. Holography system of the 45-m telescope



contour interval = 100µm

Figure 3. Surface profile contour maps before level difference adjustments



contour interval = 100µm

Figure 4. Surface profile contour maps after level difference adjustments

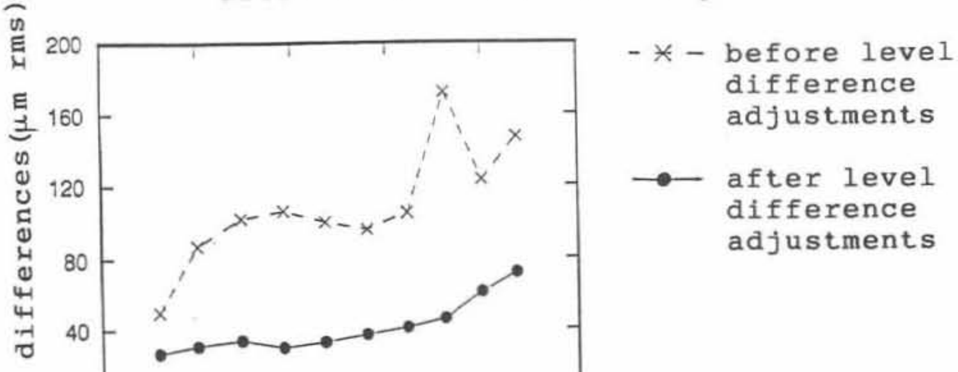


Figure 5. Radial dependence of level differences