The study of the phase retrieval holography measurement for the Ritchey–Chrétien telescope
（Ritchey–Chrétien 望遠鏡の位相回復ホログラフィー測定の研究）

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Summary

This thesis presents the study of near-field Phase Retrieval Holography (PRH) for the primary surface alignment of Antarctic 10-m Terahertz Telescope (ATT) project. Antarctica plateau is regarded as the best site for THz and sub-millimeter observations on earth for its excellent observing window at THz frequencies (high altitude, cool circumstance, dry air), which is essential for THz astronomy. Therefore, we plans to construct ATT there. The candidate of the site of ATT is Concordia Station at Dome C set up by France and Italy, or Dome F (Fuji) with higher elevation.

Surface accuracy is a key point to decide the aperture efficiency of the designed antenna. The surface alignment is essential for any types of radio telescopes to get high surface accuracy. Considering of the extreme conditions in Antarctic, near-field phase retrieval holography (no additional instruments, convenient operating) is a suitable method to measure the surface accuracy of ATT. ATT is designed as a Richey-Chrétien (RC) telescope which is evolved from classical Cassegrain telescope to decrease coma and spherical aberrations and to acquire wide field of view (FoV) for THz observations. Since the primary surface of RC telescope is consisted of a hyperboloid rather than a paraboloid, the optical features between them are different and the conventional phase retrieval holography method cannot be used for RC telescopes. Therefore, we investigate the requirements for the application of the phase retrieval holography to RC telescopes and achievable accuracy of the surface measurements.

Firstly, in radio holography, surface error is derived from the wave-front error on aperture plane. Many previous researches have shown the relationship between those two errors for paraboloid surface in Cassegrain system. We study the geometrical structure of RC telescope, and derive the surface error formula for hyperboloid surface or RC telescope.

In near-field radio holography, the phase distribution over aperture is derived from the detected near-field radiation pattern. Before making holography, the phase error from optical path variation over aperture should be eliminated as much as possible by shifting the feed or the secondary mirror. Firstly, we utilized the equivalent-paraboloid for ATT to check the calibration by moving feed and the results showed that the change of the path-length error is small. Then, we have to consider shifting the secondary mirror in ATT model. Two ways are used to check the calibration for the shift of the secondary mirror; one is the basic ray-tracing method to draw the optical ray from a near-field point source, and the other way refers to the study of path error formula from offset of secondary mirror by Ruze. We compared these two methods, and found that the difference between them can be ignored in ATT model. Then, we adopt Ruze-formula to compute the path-length error which is used to correct the defocusing phase error over aperture in near-field radio holography.

In this thesis, we adopt near-field PRH based on a numerical algorithm, named Misell-algorithm, in which more than two beam patterns are obtained by moving the secondary mirror to different position and the known offset of the secondary mirror are used to retrieve the initial aperture phase distribution by iterations. We make two different kinds of models to check the accuracy of surface measurement by near-field PRH. One is to get the field pattern at in-focus and out-focus position and the other is to get three out-focus positions (one position is located at optimum defocusing point of the secondary mirror, others are near to the previous position). In both models, we utilize the simulation software GRASP8, and set up a 100GHz Gaussian feed with edge taper of -12 dB at system's focal point to obtain the near-field pattern with 3001.1 m away from the 10-m THz telescope by physical optics method. The sampling point is 128 in both aperture plane and beam plane. In order to check the surface accuracy on distortional surface, a pair of panels are set up with offset of 50 μm and 120 μm. The rms surface error of initial model is 23.5 μm. We use ray-tracing method to decide the edge of aperture map by cutting the large phase error at edge. For 3 km-model, this value is 4747 mm in radial distance.

Next, for in-focus and out-focus model, we set totally 13 different offset values of the secondary mirror to check the near-field Misell algorithm, from 5.5 mm to 25 mm (about 1.8 wavelengths to 8 wavelengths). We find that the data processing after phase unwrap and defocusing phase error fitting by Ruze-formula includes some confusion of phase error, even though the positions of distortional panel could be easily identified. Such phase error is consisted of the secondary mirror's diffraction, calculation error from Misell-algorithm, higher orders of phase term in Fresnel integral, calculation errors from GRASP, and other errors unknown. In order to remove such phase error pattern, we try to use a perfect surface model and make a same data process. The confusion in the final phase map is similar to the one in distortional model. After get the subtraction of the aperture phase between the ideal and distortional surface model, the confusion of the phase error is reduced to a certain extent. The secondary mirror's diffraction in distortional surface is also removed by this way. It is advantage for low frequency holography. After the new version of data processing, we found that the measurement accuracy is reached to about 10 μm. And for three out-focus method, by using the same data processing, the best measurement accuracy is reached to 11.7 μm. These results show that we can get required accuracy of surface measurements for the ideal cases without noise.

Finally, we estimate the required signal to noise ratio for 3 km-model by adding Gaussian white noise into the intensity data from GRASP. The results show that the SNR should be at least 65 dB (measurement accuracy is about 11 μm) for simulations and perhaps more than 70 dB for real measurements.