Holographic Measurement System for the CCAT-prime Telescope – System Design and Novel Software Approach

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We here describe a plan for measuring and setting the reflector surfaces of the CCAT-prime telescope [1]. The most effective technique for measuring large mm-wave telescopes is "holography" [2], where the errors in the surfaces are inferred from measurements of the amplitude and phase of the beam pattern. For CCAT-prime, however, the very high surface accuracy (goal 7um), together with the crossed-Dragone optical design [3], which consists of two large off-axis reflectors, presents significant new challenges.

To reduce systematic errors, due to e.g. phase deviations in the feed horns, we use a higher frequency (~300GHz) than in previous systems. A coherent source will be securely located about 300m up-slope of the telescope to minimize atmospheric propagation errors. The signal will be collected by a receiver slightly behind the nominal focal plane and a reference receiver will be located on the telescope yoke. We will scan the antenna rapidly to provide frequent calibration of the instrumental phase and amplitude.

The holography technique exploits the Fourier transform relationship between the beam pattern and the aperture fields. The standard approach is to perform and inverse FT on the data. This method is however not well suited to the CCAT-prime case, because it cannot easily discriminate between the errors contributed by the two surfaces. To avoid this difficulty, we chose to treat it as an inference problem.

We can easily do the 'forward' calculation (simulation of the far or near-field beam patterns based on any given set of errors of the two reflectors.) Therefore, by least square fitting, we can find the set of errors which produces the simulated beam map that best fits the measurement data. In order to break the degeneracy between the two surfaces and to get the unique solution of the errors in both mirrors, we will do the measurements with the holography receiver at several different positions in the telescope focal plane.

The least-squares fitting will typically require a few thousand iterations, so the 'forward' calculation must be very efficient. We implement it using scalar diffraction theory with some simplifying approximations which make the calculation much faster than full electro-magnetic simulation, e.g. by a software package such as GRASP.

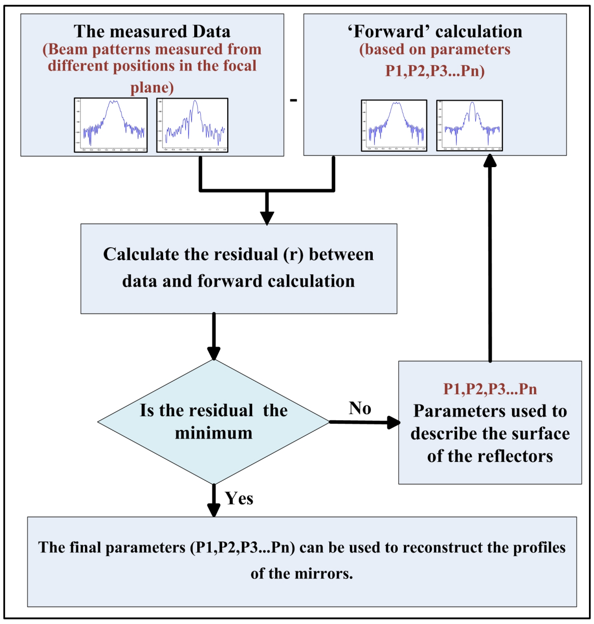

Fig. 1. The flow of calculation for the holography software.

The full solution, involving at least 3 and probably 5 beam maps, each with more than 1000 phase and amplitude data points, and fitting for 5 adjusters on each of ~70 panels on each mirror, as well as ~10 measurement parameters per beam map, is however a significant computational challenge.

The presentation will report on progress in achieving this by exploiting recent developments in software techniques, along with the results of simulations showing the accuracy that is expected.

REFERENCES

[1] S. C. Parshley et al., "CCAT-prime: a novel telescope for sub-millimeter astronomy", *SPIE Conference Series,* vol. 10700E..5XP, 2018.

[2] J. Baars, et al., "Near-Field Radio Holography of Large Reflector Antennas", *IEEE Trans. Antennas Propagat*. vol. 14, no. 4, pp. 24–41, Oct. 2007.

[3] S. C. Parshley et al., "The optical design of the six-meter CCAT-prime and Simons Observatory telescopes", *SPIE Conference Series,* vol. 10700E..41P, 2018.

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