Far-sidelobe Measurements of LiteBIRD Low Frequency Telescope 1/4-Scaled Model

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***Abstract*—LiteBIRD is a satellite for polarization observation of the Cosmic Microwave Background. We have carried out near-field antenna pattern measurement of one of its telescopes, the Low Frequency Telescope, in 1/4 scale. We have investigated the far-sidelobes at the center and at the edges of the 20-degree field of view. The measured far-sidelobe patterns are consistent with the simulated one at −50 dB level, and the patterns for two orthogonal polarization directions are consistent with each other down to −40 dB level.**

***Index Terms*—Antenna pattern measurement, Cosmic Microwave Background, Far-sidelobes, LiteBIRD.**

I. Introduction

THE footprints of the inflationary universe are expected to be observable as a unique polarization pattern of the Cosmic Microwave Background (CMB). To detect faint polarization signals at large angular scales, space observation in broad frequency bands with a wide Field of View (FoV) is demanded. LiteBIRD is the only space mission for the CMB observation in 2020s [1], [2], and the Low Frequency Telescope (LFT) is being developed as one of its telescopes. The frequency range of the LFT is 34–161 GHz and the aperture diameter is 400 mm. A crossed-Dragone design for the LFT has been investigated in the former studies [3], [4].

This study aims to examine the optical performance of the LFT and especially focuses on the measurement of its far-sidelobes, which cause contamination of the CMB signals with strong radiations from the Galactic plane.

II. Measurement Setup

We have conducted antenna pattern measurement of the LFT in 1/4-scale, so that quick iteration of the optical design can be easily made. The scaled LFT was designed and built at the machine shop of Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency. It has a focal plane area of 100 mm × 50 mm to cover its FoV of 20° × 10°.

To measure the far-sidelobes over the wide FoV, we developed a near-field antenna pattern measurement system [5] based on a vector network analyzer (Fig. 1). Antenna patterns were measured at three positions of the focal plane. For each position, the measurement was conducted for two orthogonal polarization directions named H-pol and V-pol. The measurement wavelength were also scaled to 1/4 size, and 140, 160, 180, 200 and 220 GHz have been chosen as the measurement frequencies. This frequency range roughly corresponds to the lowest frequencies of the LFT bands, 35–55 GHz, at which larger far-sidelobes are expected due to diffraction.

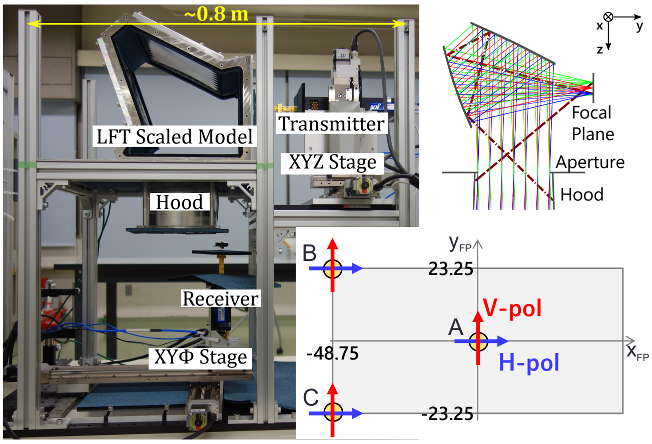

Fig. 1. (*left*) The 1/4-scaled model of LFT and its near-field antenna pattern measurement system. A conical horn with the transmitter of a vector network analyzer is placed at three positions on the focal plane of the scaled LFT with the XYZ stage, as shown in the *lower right* panel. A probe horn with the receiver measures both the amplitude and phase distributions near the aperture with the XYΦ stage. Note that this arrangement is a time-reversed configuration of a real CMB observation. (*upper right*) The ray diagram of the scaled LFT. The dashed and dot-dashed lines represent two types of stray light, direct paths and three-time reflected paths, both of which are reduced at the hood.

III. Results and Discussion

One of the causes of the far-sidelobes is stray light, such as the rays coming from the sky to the focal plane through direct paths and three-time reflected paths. Such stray light is designed to be reduced at the hood, as shown in Fig. 1. To confirm the effects of the hood, we measured far-sidelobe patterns of the scaled LFT without and with the hood, and compared them with a simulated pattern that predicts the far-sidelobes without any stray light. The results are shown in Fig. 2. Note that θ_x and θ_y in Fig. 2 are the arcsines of the spatial frequencies in x and y directions, respectively. The simulation calculates the propagation of the electromagnetic waves based on [6, Eq. 1.22].

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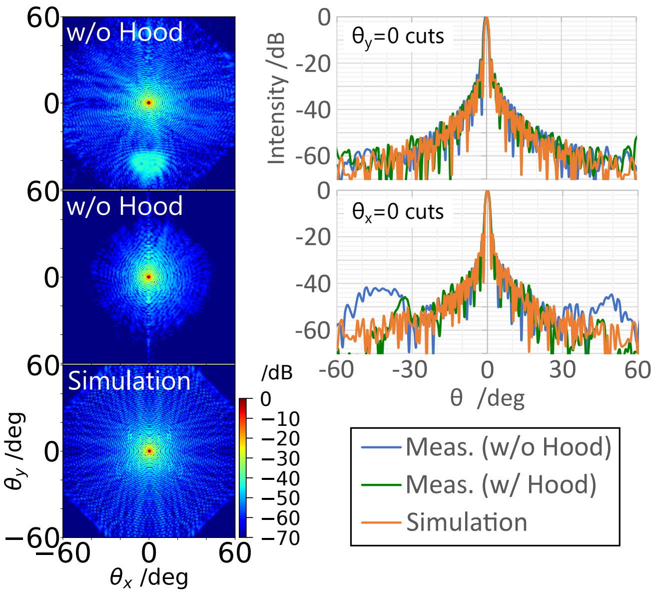

Fig. 2. The far-sidelobe patterns measured without and with the hood, and a simulated beam pattern at Position A. The simulation predicts the far-sidelobe pattern without the hood nor any stray light. The measurements and simulation are at 140 GHz, which corresponds to 35 GHz of the full-scale LFT. For without-hood case, sidelobe components are observed around $\theta_y = -45°$ and $\theta_y = 50°$. For with-hood case, these far-sidelobe features are drastically reduced, and the measured far-sidelobe pattern agrees with the calculated one at down to -50 dB level.

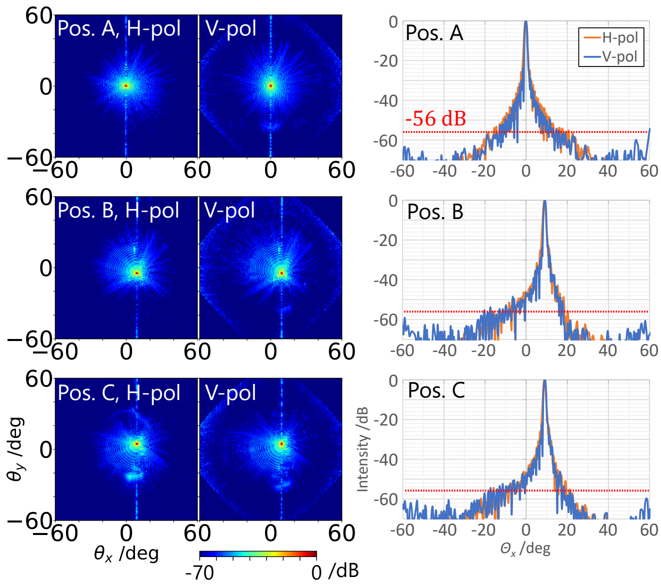

Fig. 3. H-pol and V-pol far-sidelobe patterns at each feed horn position of A, B and C, measured at 220 GHz (corresponding to 55 GHz), and their cuts in θ_x direction.

For without-hood case, two sidelobe components with the peak level of nearly -40 dB are observed around $\theta_y = -45°$ and $\theta_y = 50°$. These two far-sidelobe features correspond to the predicted direct paths and three-time reflected paths, respectively, and they are reduced by around 20 dB when measured with the hood. The measured far-sidelobe pattern with the hood agrees with the simulated far-sidelobe pattern without stray light at down to -50 dB level.

Far-sidelobe patterns measured at the three positions on the focal plane are shown in Fig. 3. The peak angles of each beam are at $(\theta_x, \theta_y) = (0°, 0°)$, $(9°, -5°)$ and $(9°, 5°)$ for the Positions of A, B and C, respectively. The measurements show that far-sidelobe patterns of two orthogonal polarization directions, H-pol and V-pol, are consistent with each other at down to -40 dB level, even at the edges of the focal plane. For both polarization directions, most of the far-sidelobes outside of $\sim \pm 25°$ are suppressed below -56 dB level. Some small-scale far-sidelobe features in $\theta_x \sim 0°$ direction are considered to be caused by the remaining stray light. Also, in each map, a vertical feature with a level of around -50 dB is found at $\theta_x \sim 0°$. This feature has been identified as near-field scanning noise caused by phase variation.

IV. Conclusion

We have conducted far-sidelobe measurement of the LiteBIRD LFT in 1/4 scale. We have confirmed that some far-sidelobe features are due to stray light and are drastically reduced by the hood, and that other far-sidelobe components are mostly less than -56 dB. We have also found that the far-sidelobe patterns for H-pol and V-pol agree with each other down to at least -40 dB level.

Minute description on the measurement setup as well as more results and analysis, including the measurements of the cross-polarization of the LFT, will be presented in the full paper [7].

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