Study of anti-reflection layer on dielectric lens for the new 72–116 GHz 7-beam receiver of the Nobeyama 45-m telescope

Yasumasa Yamasaki[1], Yutaka Hasegawa[1], Toshikazu Onishi[1], Hideo Ogawa[1], Atsushi Nishimura[2], Ken'ichi Tatematsu[2], Alvaro Gonzalez[3], Hiroaki Imada[3], Keiko Kaneko[3], Ryo Sakai[3], and Takafumi Kojima[3]

We have developed a new 7-beam heterodyne receiver "7BEE" (7BEamEquipment) for the 72–116 GHz radio frequency (RF) band and installed in the Nobeyama 45-m telescope. This receiver could become an upgrade of current receivers, such as "T70" covering the 74–89 GHz band and "FOREST" (FOur beam REceiver System on the 45-m Telescope) covering the 80–116 GHz band [1]. The main scientific purpose of this development is to understand the early stage of star formation by deriving the deuterium fraction of dense cores.

The optics for this receiver employs wideband corrugated feed horns covering the 67–116 GHz band [2] and dielectric lenses to couple the beams from the feed to those from the 45-m antenna. One of the important aspects in the lens design is the anti-reflection (AR) layers used to mitigate reflections at the lens surfaces. Several types of AR layers using different geometrical shapes have been studied in [3]. In the comparison between the concentric grooves and the straight grooves, it was confirmed that the concentric grooves caused distortion of the wavefront of the incident wave and degraded the beam symmetry, cross-polarization characteristics and aperture efficiency. In addition, when the spacing between straight grooves was compared between 1.2 mm and 1.7 mm, almost the same results were obtained for the beam pattern symmetry and noise contribution. On the other hand, the aperture efficiency was several percent higher in the case of 1.7 mm. Therefore, straight grooves with a spacing of 1.7 mm were determined as the AR structure of the lens.

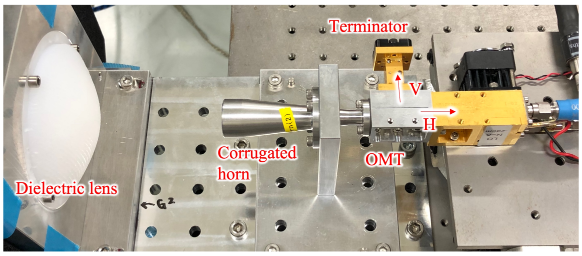

Fig. 1. Photograph of the beam measurement system.

Next, we have investigated the polarization characteristics of the AR structure of the lens. We have constructed the optical system consisting of the lens, the corrugated horn, the double-ridged waveguide type Orthomode Transducer (OMT), and the waveguide transition from circular to square waveguide with a width of 0.73 mm for the evaluation (Fig. 1). The far-field beam patterns were measured by using the beam measurement system [4]. The OMT has high performances with the insertion loss of –0.2 dB or better, the return loss of 22 dB or better, and the cross-polarization separation of –40 dB or better. We have also measured the beam patterns of the optical system in which the waveguide transition from circular to rectangular waveguide was used instead of the OMT to investigate the effect of the OMT on the beam pattern.

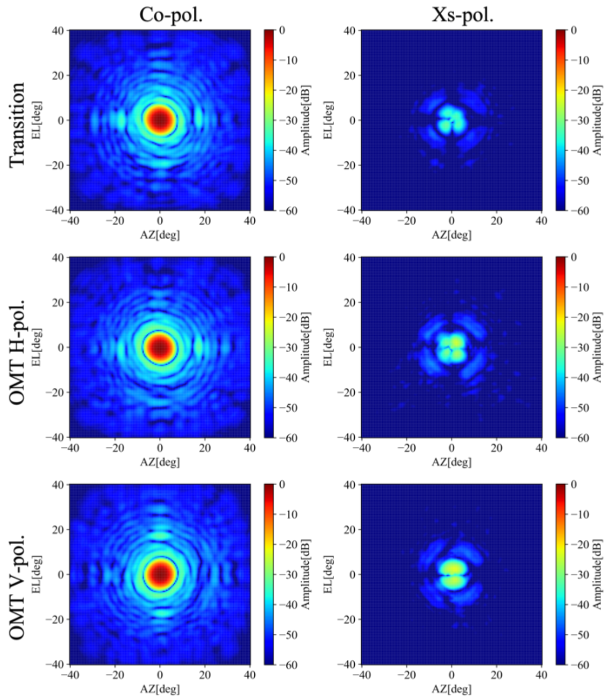

Fig. 2. Results of the far-filed beam patterns in the three cases as follows: (1) lens+horn+waveguide transition (2) lens+horn+OMT H-pol. (3) lens+horn+OMT V-pol.

The results of the far-filed beam pattern at 95 GHz were shown in Fig. 2. The aperture efficiency was calculated with the results. In the same way as the method calculated in [3], the optical systems except the lens and horn were modeled in the physical optics software GRASP (TICRA), the beam radiated from the antenna was calculated using the measurement results as the source, and the aperture efficiency was obtained from the peak gain. The results of aperture efficiency were 0.760 (transition), 0.763 (OMT, H-pol.), and 0.754 (OMT, V-pol.). The differences were within 1 %.

As for the beam pattern of cross-polarization, we analyzed it in detail because we found differences in intensity and

[1]Osaka Metropolitan University, Sakai, Osaka, Japan; [2] Nobeyama Radio Observatory, National Astronomical Observatory of Japan, Minamisaku, Nagano, Japan; [3] National Astronomical Observatory of Japan, Mitaka, Tokyo, Japan

distribution. The maximum cross-polarization intensities relative to the co-polarization were summarized in Table 1. In the system without the lens, an increase of about 3 dB in the cross-polarization level was observed at 115 GHz for V-pol. due to the addition of the OMT. As for the distribution of cross-polarization, the similar results were obtained for H-pol.. On the other hand, the higher-order mode of the circular waveguide may dominate the distribution on the high-frequency side of the V-pol. When the lens was installed, there was an increase in cross-polarization levels. In addition, differences were found between V-H in OMT. In particular, for the pattern of V-pol, we obtained results with two peaks rather than four. It was found that the beam characteristics after passing through the lens were changed by the nature of the electric field incident on the lens, especially in cross-polarization. However, it has little effect on aperture efficiency, which is fine observationally.

Table 1. Maximum cross-polarization intensity of the far-field beam pattern in dB.

Frequency [GHz]	75	95	115
horn+transition	-28.0	-26.3	-28.5
horn+OMT-H	-28.3	-26.9	-27.3
horn+OMT-V	-26.2	-26.9	-24.9
lens+horn+transition	-29.6	-32.6	-21.7
lens+horn+OMT-H	-27.9	-24.5	-18.8
lens+horn+OMT-V	-19.3	-22.7	-19.4

Acknowledgement

This work is supported by JSPS KAKENHI Grant Numbers JP20H05645. This work is also supported by Japan Science and Technology Agency, the establishment of university fellowships towards the creation of science technology innovation, Grant Number JPMJFS 2138.

References

[1] Tetsuhiro Minamidani, et al., “Development of the New Multi-Beam 100 GHz Band SIS Receiver FOREST for the Nobeyama 45-m Telescope”, *SPIE*, 2016.

[2] Alvaro Gonzalez, et al., “Development of receiver optics for ALMA bands 1 and 2, and possible synergies with ngVLA”, *SPIE*, Dec. 2020.

[3] Yasumasa Yamasaki, et al., “Development of seven-beam optics using dielectric lenses for a new 72–116 GHz receiver in the Nobeyama 45 m telescope”, *Publications of the Astronomical Society of Japan*, Mar. 2023.

[4] Alvaro Gonzalez, et al. “Reconfigurable Near-Field Beam Pattern Measurement System From 0.03 to 1.6 THz”, *IEEE Trans. Terahertz Sci. Technol.*, 2016.