Design and Manufacturing of Elliptical Aperture Antenna at Submillimeter Wavelengths for JEM/SMILES

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1. Introduction

Superconducting Submillimeter-wave Limb-emission Sounder (SMILES), which is to be aboard the Japanese Experiment Module (JEM) on the International Space Station (ISS), will observe submillimeter-wave spectra from stratospheric molecules using the limb-emission sounding method, so as to understand ozone destruction reactions [1][2]. Fig.1 outlines the SMILES payload. Fig.2 explains the limb-emission sounding method with a vertically scanning antenna.

This paper describes the electrical design and manufacturing of a submillimeter antenna (ANT) that is one of key components of SMILES. The role of ANT is to receive submillimeter wave (624.32GHz-650.32GHz) of the limb emission and transmit it to a submillimeter receiver (SRX). The optimum design of ANT has been performed, while keeping its shape within a restricted volume in SMILES, with aims of achieving a high beam efficiency, low side lobe levels, high thermal stability and the beam scanning capability in the direction of altitude.

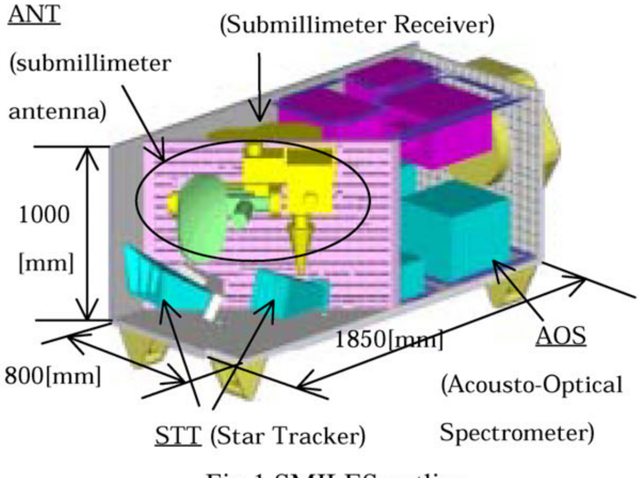

Fig.1 SMILES outline

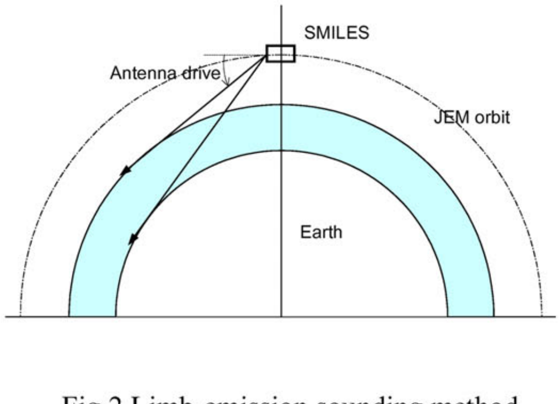

Fig.2 Limb-emission sounding method and scanning.

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2. Configuration of ANT

Fig.3 shows the configuration of ANT. The ANT consists of six reflectors: main reflector (MR), sub-reflector (SR) and a beam transfer section composed of four reflectors (RM1 to RM4). An offset-Cassegrain configuration is applied for MR and SR to reduce a blocking loss. MR has an elliptical aperture of 400 mm (vertical)×200 mm (horizontal), which is designed so that it can fit in the payload envelope completely even with the full extent of its rotation and meet the requirement of high resolution in the direction of altitude. SR is shaped to provide an elliptical illumination on the MR. RM2 and RM3 are reflectors of quadric surface of revolution, and RM1 and RM4 are flat plates. All reflectors are made of aluminum. BBH (Back to Back Horn) is a feed of corrugated conical waveguide that is specified as an interface between ANT and SRX. For receiving atmospheric limb emissions at tangent altitudes from 10 km to 60 km continuously and periodically, ANT has a reflector driving system with a stepping motor to rotate the reflector from 0 to -35 degrees. The rotation axis is exactly aligned on the beam axis between RM1 and RM2, so that no degradation will occur when the MR and SR subsystem is rotated. Furthermore, a novel concept of thermal similarity deformation is introduced to decrease the antenna performance degradation in orbit [3].

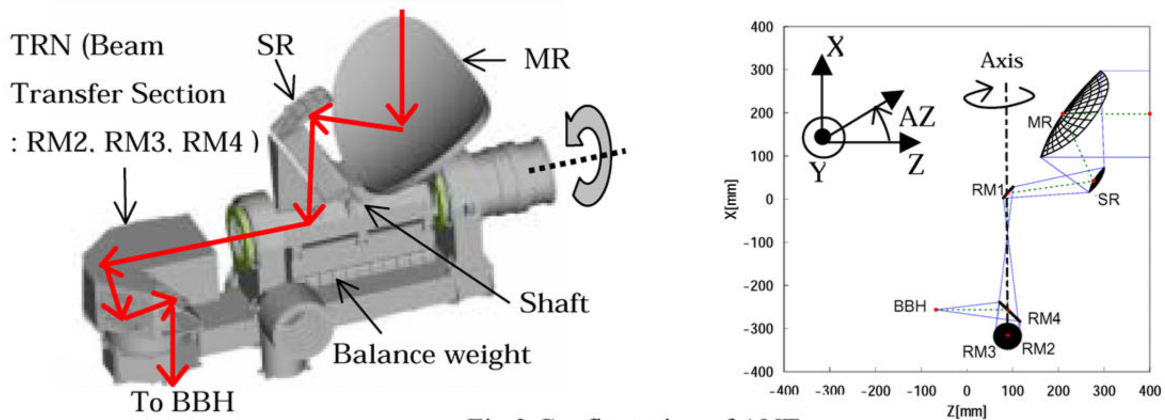


Fig.3 Configuration of ANT

3. Electrical design

To satisfy the requirements of high beam efficiency, low transmission and spillover losses, the edge illumination levels for mirrors from RM1 to RM4 are designed less than –50 dB. Also, those of MR and SR are designed less than –30 dB. Furthermore the physical aperture size of SR is larger than the size of illumination area of –30 dB, so that the SR spillover is suppressed and the remaining reflected component goes out behind MR. This is to keep the SR spillover from looking at the Earth's atmosphere and deteriorating observation characteristics. The F/D ratio (F: focal distance, D: aperture diameter) of each reflector is selected large enough to reduce performance degradation due to alignment errors. To analyze the antenna performance, the beam mode expansion method is applied for the beam transfer section from RM1 through RM4, while the geometrical optics method and physical optics method are used for SR and MR, respectively [4]. An ideal HE11-mode feed (straight corrugated waveguide: ϕ 8.65 mm) is assumed for the BBH feed. In the nominal design, degradation factors such as manufacturing errors, alignment errors and thermal distortions are not taken into account. The characteristics of nominal beam patterns are summarized in Table1.

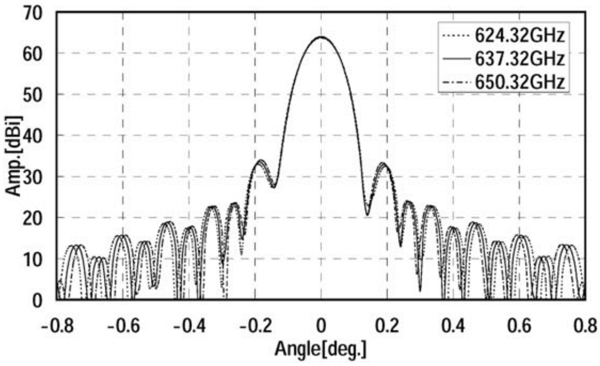
Table1 The characteristics of nominal beam patterns @637.32GHz

Item	Characteristic
Antenna type	Offset Cassegrain
Aperture size	400mm × 200mm
Beam efficiency	97.3%
Beam width (EL)	0.09°
Beam width (AZ)	0.17°
Side lobe level	Less than –25dB

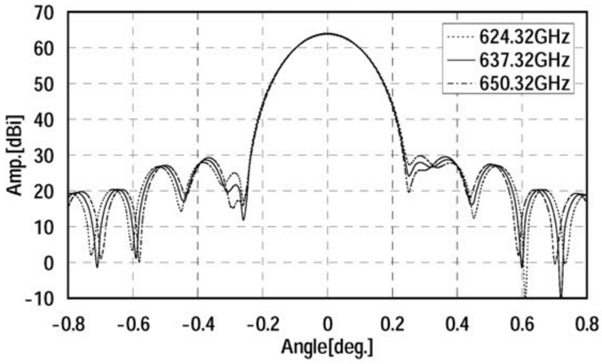
$$Beam\,efficiency = \frac{\iint_{\Omega} P(\phi,\varphi)\sin\phi d\phi d\varphi}{\iint_{4\pi} P(\phi,\varphi)\sin\phi d\phi d\varphi}$$

where P is the electric power radiated in a unit solid angle in the direction of ϕ and ϕ, and Ω is an elliptical solid angle area whose long and short diameters correspond to 2.5 times the half-power beamwidth (HPBW) of the main-lobe.

Required frequency band for SMILES is from 624.32 GHz (lowest freq.) to 650.32 GHz (highest freq.). The nominal design is performed at the center frequency of 637.32 GHz. In order to confirm the frequency characteristics, radiation patterns for 624.32 GHz and 650.32 GHz are calculated. The radiation patterns are indicated in Fig.4, which shows that the ANT meets the requirements on the frequency band.



(a) EL cut pattern



(b) AZ cut pattern

Fig.4 The radiation patterns at 624.32GHz, 637.32GHz, and 650.32GHz.

4. Manufacturing

Fig.5 shows manufactured Engineering Flight Model (EFM) of ANT. Surface data of six reflectors were measured by three-dimensional measurement machine, and surface errors are obtained from the design data and are shown in table 2. It is found that the surface errors are small and the accuracies of these surfaces meet the requirements.

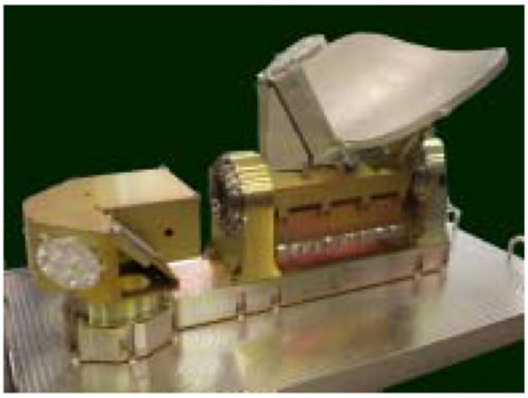
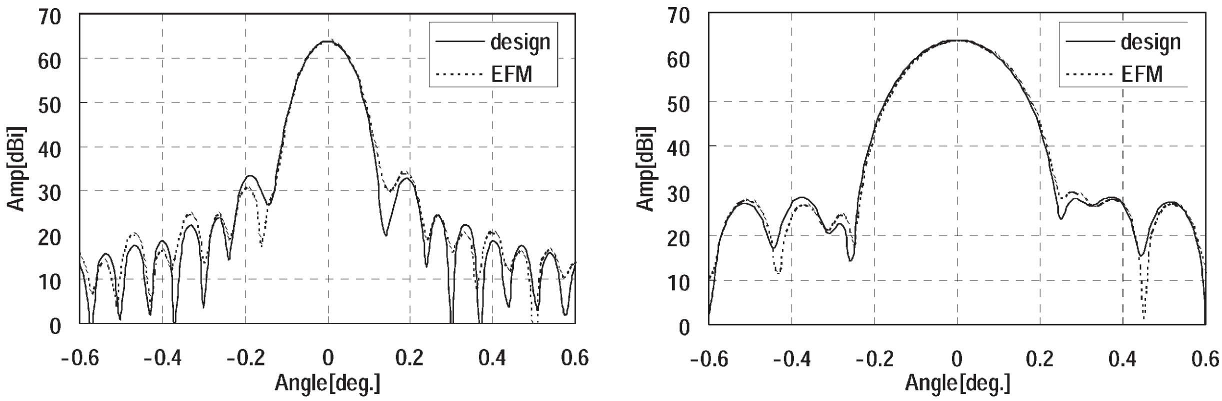


Fig.5 EFM of ANT

Table2 Surface errors (r.m.s.)

	Surface errors[μ m]
MR	7.3
SR	3.8
RM1	0.5
RM2	1.9
RM3	2.1
RM4	0.6

To verify the surface accuracy of EFM, the estimation of radiation patterns are executed using measured surface data of MR and SR which have influence on radiation pattern degradation than that of other reflectors. Fig.6 shows the comparison of design and estimated radiation patterns and good agreements can be seen. From these patterns, validation of surface accuracy of EFM has been confirmed.



(a) EL cut pattern (b) AZ cut pattern

Fig.6 The radiation patterns of EFM at 637.32GHz

5. Conclusions

The design and manufacturing of the submillimeter antenna (ANT) of SMILES has been presented. The design of ANT successfully foresees that the SMILES antenna will satisfy the antenna requirements that are high beam efficiency, low side lobe levels and the beam scanning capability in the direction of altitude, while keeping its shape within a restricted volume in SMILES. Furthermore, EFM of ANT has been manufactured and surface data were measured. Surface accuracies of reflectors are evaluated and availability of manufacturing has been confirmed from the estimation using EFM surface data. Antenna radiation patterns will be measured in the future.

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