Abstract

A light weight and very high gain radial line slot antenna (RLSA) for space exploration is designed, fabricated and characterized at 32GHz. More than 25000 slots are spirally arranged on the metal top plate with the uniform distribution over the aperture of 900mm diameter. The use of the honeycomb as the spacer in the parallel plate is indispensable because of its lightweight and compactness, though at 32GHz, this material is considerably lossy and also anisotropic if the cell size is too coarse.

Keywords: Radial Line Slot Antennas, High Gain, Honeycomb Structure, Space Exploration.

1. Introduction

The conventional radial line slot antennas (RLSAs) are well-known as high-gain, high-efficiency planar antennas which generate the circular polarization. In 1980s, it was designed and practically used as DBS reception around the frequency range of 12GHz [1]. In 2010, an RLSA with honeycomb structure was attached to the satellite which travelled toward the sun as part of a space exploration project called PLANET-C [2]. Because of its proven characteristics and historically successful applications as satellite broadcasting antennas, RLSA is considered as the most attractive candidate for substituting the reflector antennas, which so far has been widely used as on-board antennas.

Even though the high gain RLSA for space use was successfully designed and characterized at 8.4GHz in the past, this time the four times higher frequency-32GHz is still very challenging in terms of the fabrication accuracy. In addition, the very high gain of 44.1dBi is required which enhances the sensitivity upon the fabrication errors in the antenna. Another difficulty is that at 32GHz, the honeycomb structure has not been proven well in terms of loss, uniformity and isotropy. Several test models are designed and analyzed by the Method of Moment (MoM), fabricated and characterized by the Near-Field Measurement (NFM). The measured antenna gain is about 44.6dBi at the desired frequency 32.0GHz, which meets the requirement. The measured loss is about 4dB, in which the material loss of the honeycomb is the dominant loss factor.

2. Structure of RLSA with Honeycomb at 32GHz

The RLSA consists of a honeycomb core, which is attached to a metal bottom plate and a coated copper skin by a thin layer of adhesive. Above the skin layer, thousands of slots are etched on the metal top plate to radiate the field propagating inside the waveguide. The skin is used as a buffer layer between the thin slot plate and the under layers. Figure1 shows the structure of the RLSA, while the antenna specifications and parameters are elaborated in Table 1.
3. Design and Analysis

3.1 Equivalent Model to the Waveguide Structure

The 4 layers waveguide structure of this RLSA (as shown in Fig. 1) is in fact very complicated for analysis, especially when it comes to an oversized RLSA with 900mmφ and thousands of slots. Authors develop an equivalent 2 layers model which can sufficiently replace that complex 4 layers structure. Equivalent model gives both the actual propagation constant for the TE cylindrical wave if not for slots and the actual slot coupling (radiation as well as the reflection). Fig.2 shows the structure and parameters of this equivalent model. A small test antenna with 300mmφ is designed and characterized by NFM to confirm the reliability of this 2 layers model. The good agreement in term of the frequency characteristics between the measurement and the prediction by MoM shown in Fig.3 gives a strong evident that this equivalent mode can be used as a replacement for the real waveguide structure.

3.2 Slots Design and Analysis using Equivalent Model

The slot array design procedure is similar to that of the conventional RLSA [3], given that the waveguide structure is now simplified to 2 layers equivalent model as described in section 3.1. Figure 4 shows the desired coupling and slow wave factor as functions of slot length, predicted by MoM, while Fig. 5 shows the slot length distribution which synthesizes the required coupling distribution in Fig. 4. The azimuthal spacing between pairs of slots is 0.6λ0. More than 26000 slots arranged in 52 spiral turns are distributed on the 900mmφ aperture.

3.3 Evaluation of the Antenna Performance

This RLSA, with more than 26000 slots and complex waveguide structure, is mathematically too large to be analysed as it is even with super computer. Therefore, the authors have to search for alternative models to evaluate the antenna performance before going to the fabrication phase. The one dimensional slot array is developed in this sense to characterize the behaviour of the antenna in just one direction. Assuming the rotational symmetric operation as well as the illumination, we could extrapolate the behaviour of the whole antenna, from the one dimensional slot array. The rough but valuable estimation of the antenna performance could be obtained. The 2 layers equivalent waveguide structure is also performed here to analyze this 1-dimensional slot array model.

4. Measured Antenna Characteristics

4.1 Measurement Setup

The RLSA are measured at 2 sites: Tokyo Inst. of Tech. and NT-Space laboratory. Because of its large size, only the near-field measurement is conducted. The flatness of the antenna is imperfect which causes some deformation naturally. Furthermore, unlike other small antennas, the alignment of this oversized RLSA in the environment of gravity is quite troublesome. Figure 6 shows the setup before measurement at NT-Space. The antenna is stabilized vertically by a mechanical supporter at the centre of the bottom plate, facing against a pick up probe at the distance of about 4λ0. Figure 7 shows the deformation level over the antenna aperture. Maximum deformation level of 0.9mm is observed. The electric performance in the next section is obtained by theoretically compensating the flatness errors in Fig. 7.

4.2 Measurement Results for 1st version of RLSA

Figure 8 shows the measured return loss over 10GHz band-widths from 30GHz to 40GHz. In 2GHz band around the design frequency (31GHz to 33GHz), it is below -10dB. At the design frequency, the reflection is about -17dB.

Figure 9 shows the 2 dimensional aperture distributions at 31.9GHz, which indicates the highest directivity. A fine uniform phase distribution is obtained with the deviation of less than 60deg. On the other hand, the amplitude in radial direction is tapered toward the periphery. The taper level is about 10dB and 6dB in x and y-direction, which is caused by the abovementioned misalignment.
Figure 10 shows the measured radiation pattern of both co- and cross-polarization. The grating-lobe is effectively suppressed to less than -45dB. The cross-polarization at the bore-sight is -19dB with respect to the co-polarization level; in other word, the axial ratio is less than 2dB, which shows a fine quality of circular polarization.

Finally, the antenna gain and directivity are reported in Figure 11. The peak is found at 31.9GHz for both gain and directivity. At 31.9GHz, the directivity of 48.3dBi indicates a fine quality of uniform aperture illumination, while the degradation to 44.7dBi of the gain suggests the loss in the honeycomb structure is more than 3dB and the loss at the connector and cable also exist. At 32.0GHz, the measured directivity and gain are 48.3dBi and 44.6dBi, respectively.

5. Conclusion

A lightweight RLSA with honeycomb structure is designed and characterized. An acceptable uniform aperture illumination is observed, given that challenge of controlling the huge amount of slots. The directivity of 48.3dBi is the results of that uniform aperture illumination. The degradation of the antenna gain to 44.6dBi is the biggest obstacle since the loss of the honeycomb structure at 32GHz band is inevitable.

References
