Study of a High Gain Radial Line Slot Antenna in Ka-band for Space Uses

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***Abstract* — A slot array design for a very high gain of more than 44dBi RLSA was reported in this paper. A conventional slot array design procedure based on the Method of Moments (MoM) was still applied, but needed to modify in order to adapt with a very large number of radiating elements and a complex, multilayer structure of the substrate. A fast analysis method based on a simplified but reliable equivalent model of the multilayer waveguide was established to estimate the antenna performance. Finally, several RLSAs having ϕ = 900mm diameter were fabricated and characterized by the near field measurement. In the optimum case, a directivity of 48.3dBi correspond to 73% aperture efficiency was obtained at 31.9GHz, at which the measured gain was 44.6dBi.**

***Index Terms* — Multi-layer waveguide structure, Radial Line Slot Antenna, Space Uses.**

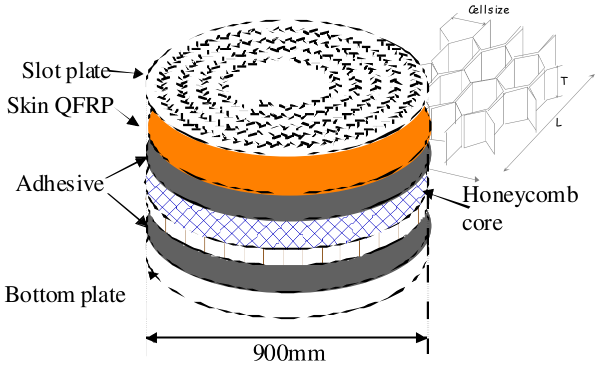

Fig.1. Multilayer- RLSA with honeycomb structure for space use

I. INTRODUCTION

Radial line slot antennas (RLSAs) are planar slot array antennas for circular polarization on oversized parallel plate radial waveguides. RLSA has been well known as a high gain, high efficiency antenna operating in high frequency ranges because of its low loss property of the waveguide.

RLSA was originally designed for Direct Broadcast from Satellite (DBS) reception around 12 GHz [1]. Due to its high gain characteristic and compact structure, RLSA has been proposed for satellite on-board antennas ever since. In 2010, a high gain and lightweight RLSA was successfully mounted on a satellite AKATSUKI as a part of a project PLANET-C [2]. Advantages of uniformly thermal deformation and structural stability have made RLSA a strong candidate for replacing the conventional parabolic antennas. With the efforts of weight reduction and mechanism stability enhancement, the use of honeycomb as a filled dielectric material inside the radial waveguide was recommended. Furthermore, in order to support the honeycomb structure which has hexagonal, hollow shape, some buffer layers having different electrical properties were included. As a result, a three-layer structure was utilized as the waveguide of the RLSA in PLANET-C [2], and it was a success in terms of uniformity, isotropy of the propagating wave and loss of the materials.

In this paper, we are challenging a new specification (a 44.1dBi gain at 32GHz), which is believed possible for a -RLSA. For that high gain and high frequency, number of radiating elements of more than 20000 is required. A RLSA having that large number of slots is, in fact, very difficult to be simulated by the conventional methods such as HFSS and/or the Full-MoM [3]. Therefore, authors have established a fast analysis/ design procedure to control the radiating elements as well as to estimate the antenna performance. By applying this procedure, we have fabricated several antennas to tune the center frequency as well as to enhance the antenna performance.

II. MULTI-LAYER STRUCTURE OF THE 32GHZ-RLSA

A RLSA waveguide structure consists of 4 layers of dielectrics that are sandwiched between the base metal plate and a thin copper plate with slots. The main part of the waveguide is a honeycomb layer, which is attached to other layers by thin layers of adhesive. Under the top plate, a layer of Quartz skin is attached to avoid a direct contact between the copper plate and the honeycomb structure. Power is fed at the center of the radial waveguide by a simple coaxial feeder. Outward travelling wave produced by the feeder radiates throughout thousands of orthogonal slot pairs that are arranged spirally on the circular aperture to obtain a pencil beam at the bore-sight. Fig. 1 shows the structure of the RLSA, while the parameters of each layer are elaborated in Table I.

TABLE I
LAYERS PARAMETERS FOR 32GHZ RLSA

Parameters			
Honeycomb core	Thickness	d_3	3.50 mm
	Permittivity	ε_{r3}	1.084
Skin	Thickness	d_1	69.0 µm
	Permittivity	ε_{r1}	3.10
Adhesive	Thickness	d_1, d_4	62.0 µm
	Permittivity	ε_{r1}, ε_{r4}	2.70
Metal plate	Thickness	T	18.0 µm

III. SLOT ARRAY DESIGN OF 90CM RLSAs

For the full slot array design, the conventional slot array design procedure [4] can still be applied. On the other hand, an analytical method to predict and optimize the antenna performance is rather complicated considering calculation time and computational load. In the past, a full MoM [3] which can analyze and predict a RLSA's performance effectively was used. However, its calculation of the slot coupling was applicable on only single layer waveguide structure. For a multi-layer waveguide structure, if the antenna size and the number of slots are relatively small enough not to create too much computational mesh, an accurate estimation could be produced by a High Frequency Structure Simulator (HFSS). This time, the antenna having both multi-layer waveguide structure and numerous amount of slot on a large aperture, contravenes both abovementioned methods to simulate the antenna performance.

In order to evaluate the antenna performance before going to the fabrication phase, a fast analysis method was developed based on the MoM for 1-dimensional linear slot array. A complex 4-layer waveguide structure was also simplified to an electrically equivalent 2-layer one. This study is well reported in another paper of the authors [5]. The basic idea is to model the 1-dim slot array on the narrow wall multilayer waveguide and analyze it using the MoM. The excitation coefficients of slots along a certain radial ρ-direction would then be extrapolated onto 2-dim spiral array with the assumption of uniformly illuminated aperture. Finally, an analytical method considering both slot lengths and excitation coefficients is applied to calculate the array directivity [6].

IV. MEASUREMENT RESULTS AND ANTENNA PERFORMANCE ENHANCEMENT

Three engineering models (EM01, EM02 and EM03) were designed, fabricated and characterized by the near-field measurement. The antennas having a 90cm diameter, each has more than 26000 slots. The NoMEX honeycomb core was used together with the coated skin and the thin layers of adhesive to create a multilayer waveguide. The first design-EM01 was used to verify the reliability of the design/ analysis procedure presented in III, while the rest, EM02 and EM03 were designed to tune the center frequency to 32GHz as well as to enhance the antenna performance.

Fig. 2 shows a photo of EM01 placed in the near-field measurement system with the scan area of 1m^2. Full scan was conducted several times to assure the repeatability of the measured data. The reflection coefficients measured by the Vector Network Analyzer (VNA) are reported in Fig. 3. It is observed that the first design- EM01 has a quite big reflection in comparison with the others. In case of EM02 and EM03, the reflection coefficients in the frequency range of our interest (31.5~32.5GHz) are less than -20dB.

Measured directivities of three models are presented in Fig. 4 by the solid lines. Dash lines, which indicate the directivities predicted by the procedure in III, are also included for comparison. In all cases, the measured results are shifted about 0.1GHz to the higher domain and the dB levels are dropped about 0.7dB. This difference might come from the assumption of a uniformly illuminated aperture distribution while extrapolating the 1-dim data in the 5th step of the design/ analysis procedure. Fig. 5 characterizes the measured gains. A 44.1dBi gain specification line is also included. Among these three models, EM02 seems to have a highest performance, with a 44.6dBi at 32GHz. This result is well explained by the measured reflection coefficients and directivities. It is also noticeable that a big degradation of about 4dB appears in the frequency range from 31.5 to 32.5GHz. Another study conducted by the authors reveals that this degradation is mostly come from the dielectric loss of the NoMEX honeycomb [7].

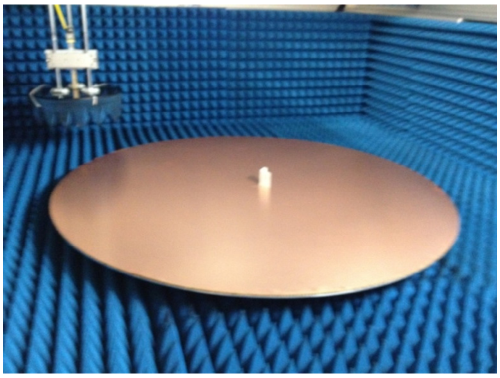

Fig. 2 A fabricated 90cm RLSA in near-field measurement

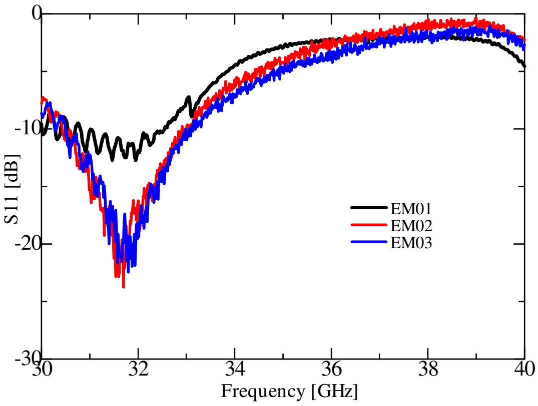

Fig. 3 Measured Reflection Coefficients

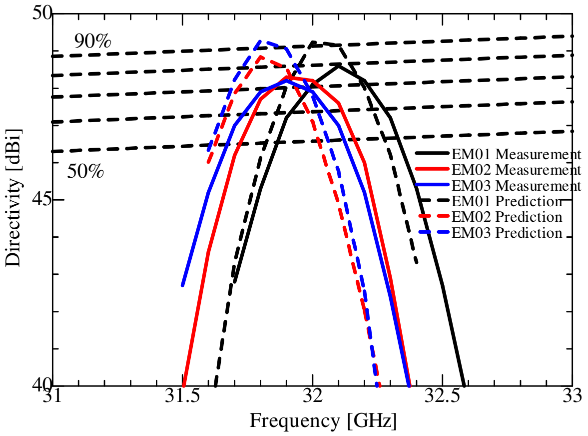

Fig. 4 Measured and Predicted Directivity

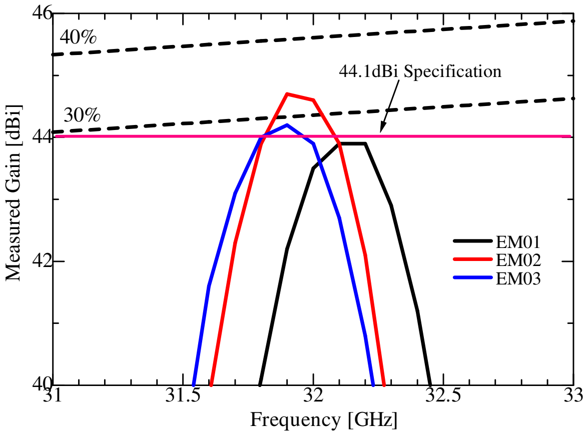

Fig. 5 Measured Gain of 3 fabricated RLSAs

V. CONCLUSION

Authors have developed a fast analysis method based on the MoM to evaluate the antenna performance. Several test antennas were designed by the conventional method and analyzed by the newly proposed procedure. The predicted and measured directivities are well agreed. The optimum design in terms of center frequency and antenna gain is EM02, with that a 44.1dBi required gain is satisfied at 32GHz. Table II summarizes all the measured performances of three fabricated model at 32GHz.

TABLE II
MEASURED PERFORMANCES OF 3 MODELS AT 32GHZ

Model	Measured reflection coefficients	Measured directivities	Measured Gain
EM01	-11.6dBi	48.35dBi	43.56dBi
EM02	-18.2dBi	48.15dBi	44.60dBi
EM03	-19.1dBi	47.95dBi	44.17dBi

ACKNOWLEDGMENT

This research is supported by the JAPAN Aerospace Exploration Agency (JAXA) and also conducted in part as “the Research and Development for Expansion of Radio Wave Resources” under the contract of the Ministry Internal Affairs and Communications.

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