A Satellite On-Board Radial Line Slot Antenna with Honeycomb Structure

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Abstract

A radial line slot antenna with honeycomb structure for satellite on-board equipment is proposed in this paper. The slot coupling with three-layer dielectric waveguide is analyzed by the method of moments and is incorporated into the design method of the radial line slot antennas. The first model with the diameter of 900mm is fabricated; the gain is 33.9dBi with efficiency of 35.5% and the reflection is -9.49dB at 8.8GHz.

1. INTRODUCTION

A radial line slot antenna (RLSA) is a high-gain, high-efficiency and low-cost planar antenna, which was originally proposed for satellite TV reception in the frequency region around 12 GHz [1]. To synthesize arbitrary dielectric constant, a RLSA with multi layered dielectrics was proposed [2, 3].

As an application of the multi layered structure, a RLSA with honeycomb structure is proposed [4]. A honeycomb is appropriate for satellite equipment because of its lightness and good heat-resistant characteristic. Parabolic antennas are often used in space, but they have possibility of thermal deformation by temperature difference between their front and back. On the other hand, the RLSA is a planar antenna, so it can be fixed by a back structure. The honeycomb structure is multi layered structure as shown in Figure 1 and the dimensions are summarized in Table 1. Table 2 shows the requested specifications.

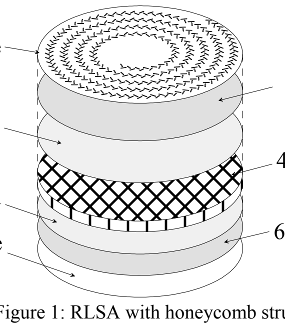

Figure 1: RLSA with honeycomb structure

TABLE 1: HONEYCOMB STRUCTURE

No.	Name	Thickness (mm)	ε_r
1	Slot Plate (Copper)	0.03	
2	Skin	0.3	3.1
3	Bond	0.062	2.7
4	Honeycomb Core	5.0	1.07
5	Bond	0.062	2.7
6	Skin	0.3	3.1
7	Bottom Plate (Copper)	0.03	

TABLE 2: REQUESTED SPECIFICATIONS

Frequency	Gain	Diameter	Bandwidth
8.4GHz	Over 35dBi	90cm	Over 5MHz

In this paper, the analysis and design of the RLSA with honeycomb structure are presented. The measured characteristics such as gain, reflection and aperture field illumination are compared with the calculated ones. Some future works to improve the gain and to adjust the center frequency are also discussed.

2. ANALYSIS AND DESIGN

An analysis method of slot coupling on the three layered radial line by using the method of moments (MoM) has been established [5]. Actually, this honeycomb structure has five layered dielectrics. Because the bond with thickness of 0.062mm is thin enough and its dielectric constant is close to the skin's one, we assume that the dielectric constant of the bond is set to equal to that of the skin so that this structure can be analyzed as three layers by the analysis method. In addition, the honeycomb core is approximated by uniform dielectric constant (ε_r=1.07).In this condition, the equivalent dielectric constant of the waveguide is 1.17.

Figure 2 shows the analysis model of a radial waveguide filled with honeycomb structure with a pair of radiating slots. It is extracted from an array on radial waveguide. It is approximated by a rectangular waveguide with periodic boundaries on the narrow walls for the internal region to simulate the uniform excitation of slot pairs in the transverse direction and another waveguide for the external region to include the mutual coupling in a uniformly-excited two-dimensional array. The analysis model is divided into canonical structures in order to derive dyadic Green's functions in each region. In the waveguide and slot regions, the dyadic Green's functions are expressed by eigen-mode expansions of hybrid modes propagating in the multi layered structure.

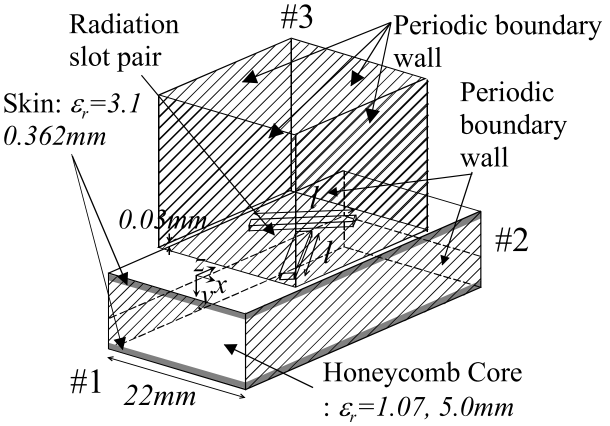

Figure 2: Analysis model of radial waveguide with honeycomb structure with a pair of radiating slots

Figure 3 shows an example of analysis results by MoM and HFSS. The slot lengths and widths are 15.66 and 1 mm, respectively. It represents good agreement between the two results and the reliability of MoM.

The RLSA is designed with S-parameters calculated by MoM in order to realize uniform phase distribution at 8.4 GHz [6]. To suppress the leakage at the open end of the radial line, the non-uniform amplitude distribution is applied to maximize the aperture efficiency [7]. The positions and the lengths of the slots in the radial direction on the original designed antenna are shown in Figure 4.

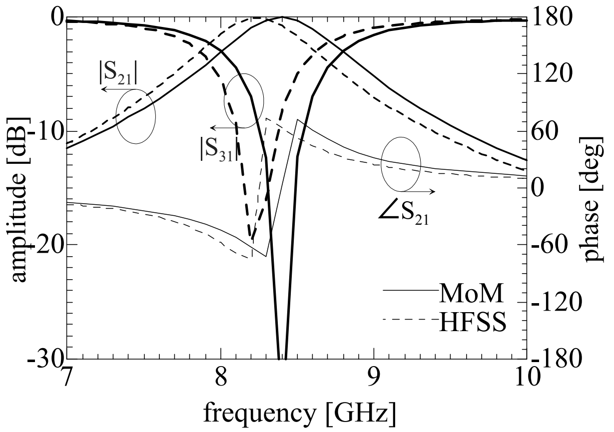

Figure 3: An example of calculated S-parameters

A coaxial feeding is used for the RLSA with a spiral array of elements. Figure 5 shows the feeding structure which is reinforced by using a ceramic cylinder with a via hole in order to fix a feeding pin tightly.

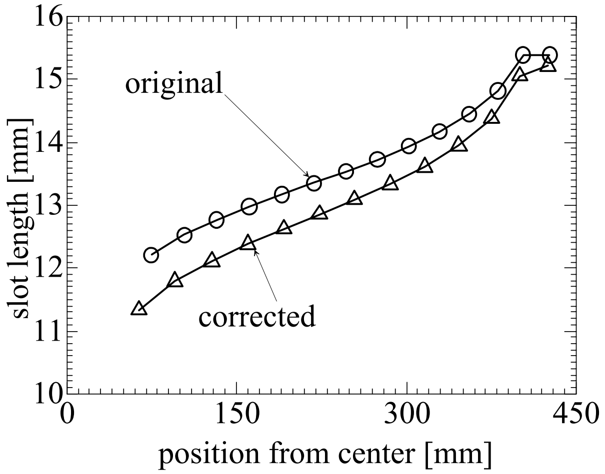

Figure 4: Positions and length of slots of designed and redesigned antennas in radial direction.

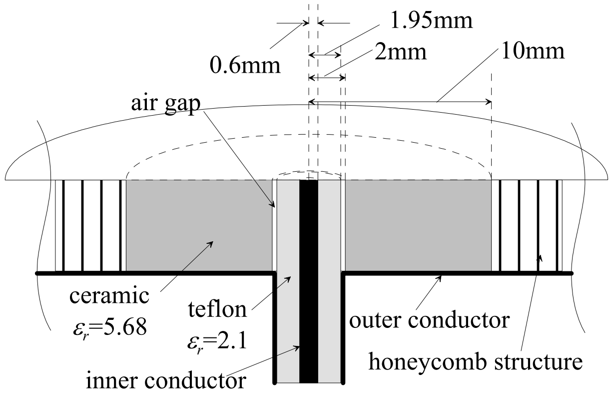

Figure 5: Feeding structure reinforced by a ceramic cylinder with via hole

3. MEASUREMENT RESULTS

The measured one-dimensional phase and amplitude distributions in the radial direction are shown in Figure 6 and 7 at 8.8 GHz at which almost uniform phase distribution is obtained. The calculated distributions are derived by cascading S-parameters of the slot pairs in the radial direction. The equivalent slot length of +0.6 mm is uniformly assumed which compensates the difference between rectangular slots in the analysis and round-edge slots in the fabrication [8]

In the phase distributions, the measurement and the calculation have a reasonable agreement. On the other hand, the measured amplitude distribution has an excessive taper of 3 dB against the uniformity of the calculated one from 80 mm to 150 mm in the radial direction. The reason of this disagreement may be due to the transmission loss in the waveguide and the error on the equivalent slot length.

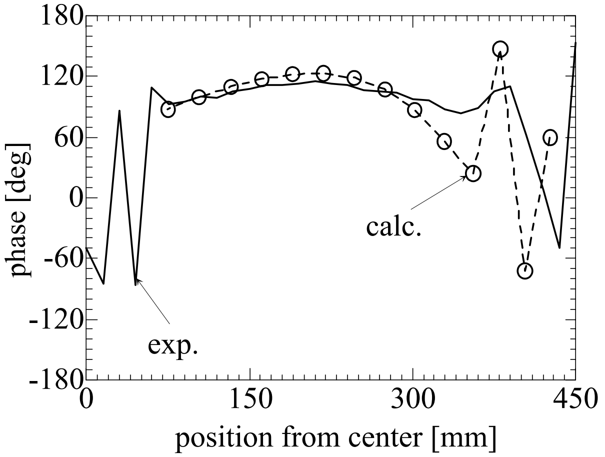

Figure 6: One-dimensional aperture phase distribution in radial direction at 8.8 GHz.

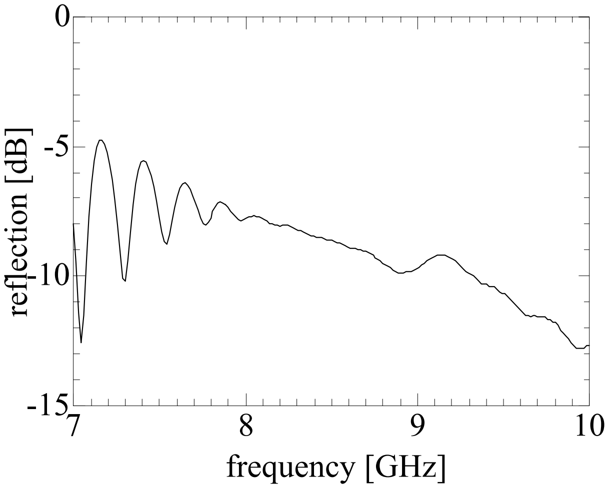

Figure 8: Frequency characteristics of measured reflection

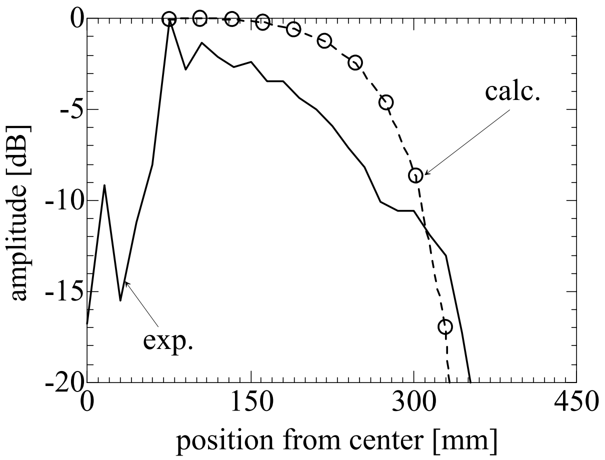

Figure 7: One-dimensional aperture amplitude distribution in radial direction at 8.8 GHz.

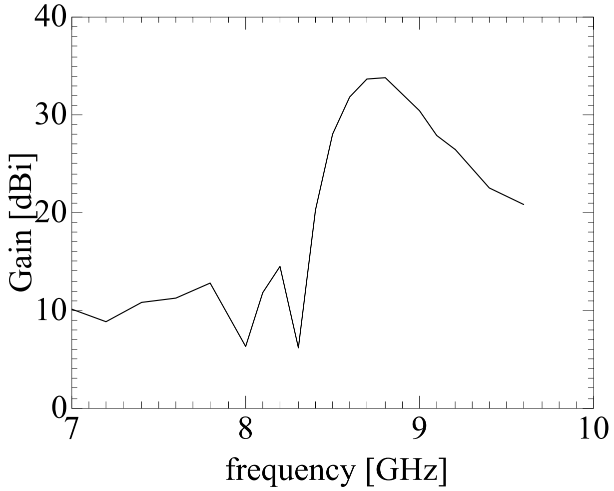

Figure 9: Frequency characteristics of measured gain

Figures 8 and 9 show the frequency characteristics of the reflection and the gain, the latter of which is obtained from the comparison with a standard horn antenna by near-field measurement as well as the far field transformation. At the designed frequency of 8.4 GHz, the gain is 20.3 dBi and the reflection is -8.46 dB. The peak gain is shifted up to 8.8 GHz, and 33.9 dBi is obtained with the reflection of -9.49 dB.

4. Dielectric Constant and Loss Measurement of Honeycomb Structure and Tuning The Center Frequency Shift,

The measured peak gain is obtained at 8.8 GHz, which is 400 MHz higher than the design one of 8.4 GHz. It may come from the error in the dielectric constant of the honeycomb structure.

Figure 10 shows the system for the estimation of dielectric constant and transmission loss of the waveguide with honeycomb structure. The upper plate has a column of small via holes with diameter of 2 mm in the radial direction. A probe should not be contact with the honeycomb not to disturb the inner fields, therefore the dielectric constant and transmission loss can be estimated precisely by measuring an S-parameter.

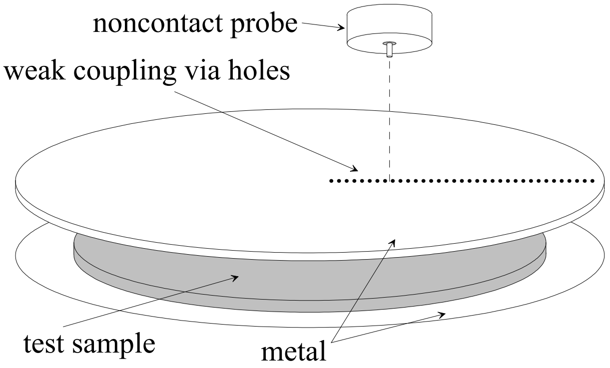

Figure 10: dielectric constant and transmission loss estimation system.

Figure 11 shows the phase and amplitude of the inner field measured from this experiment at 8.395 GHz. By the fact that a taper of the phase is -10.71 deg/mm, the equivalent relative dielectric constant of the waveguide is 1.13 which is smaller than the value 1.17 used in the design. From this result, the relative dielectric constant of the honeycomb core itself is estimated to 1.03.

In a radial waveguide, the amplitude of the cylindrical wave varies in proportion to $\rho^{-0.5}$ if not for the loss in principle. The amplitude of the inner field attenuates excessively due to loss in the honeycomb along the propagation. From Figure 11, this excessive loss is small and is about -0.003 dB/mm.

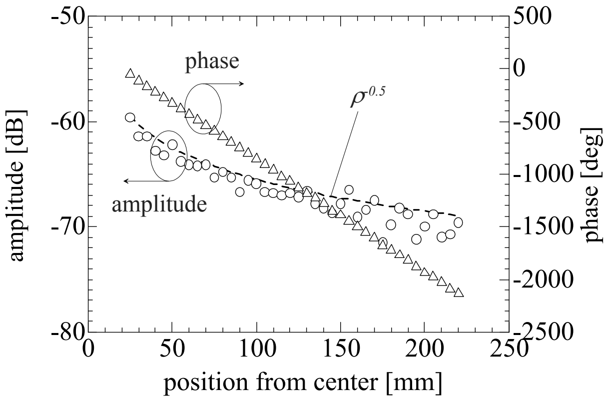

Figure 11: Phase and amplitude of Inner field in the radial direction at 8.395GHz

The slow wave factor ζ which was used at the design process for the first fabrication was erroneous and should be redesigned by using the dielectric constant measured above. It is given as the guided wavelength including dielectric constant and the transmitted phase by each slot pair as shown in the following equation.

$$\zeta = \frac{\lambda_g}{\lambda_0}\left(1 + \frac{\angle S_{21}}{360}\right)$$

We redesign the RLSA by using this revised slow wave factor. The positions and the slot lengths in the new design are included in Figure 4. They are different from the original ones as are shown in the figure.

The measured one-dimensional phase distribution in the radial direction at 8.4 GHz is shown in Figure 12. The calculated ones derived from the cascade of S-parameters of the slot pairs in the original and corrected RLSA are also represented in the figure at 8.4 GHz. A taper of the measured phase distribution in the first fabrication agrees with calculated one. On the other hand, the corrected RLSA has phase uniformity with a ripple of only 25 degrees; these will be used in the next fabrication.

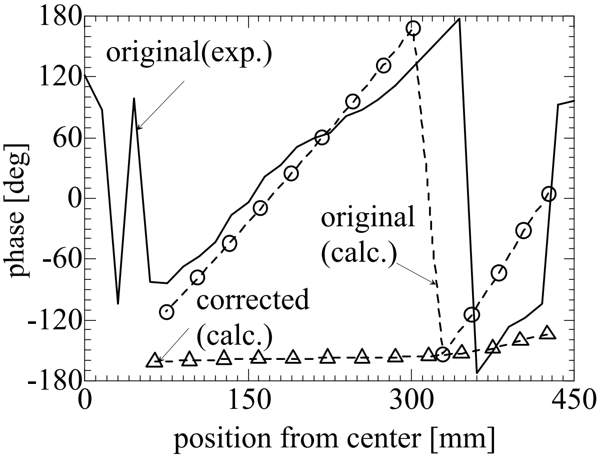

Figure 12: One-dimensional aperture phase distributions of measurement and calculation on designed and redesigned antennas in radial direction at 8.4 GHz.

5. CONCLUSION AND FUTURE WORKS

We have designed a RLSA with honeycomb structure at 8.4 GHz. The measured peak gain is 33.9 dBi at 8.8 GHz.

Estimation for honeycomb characteristics shows that the relative dielectric constant of the honeycomb core is 1.03 and transmission loss is -0.003dB/mm.

As the future study, the center frequency should be tuned by using the correct definition of the slow wave factor. The dielectric constant of honeycomb, the equivalent slot length and the propagation loss also should be reflected in the design. The potential antenna efficiency is around 50%-60%.

REFERENCES

[1] N. Goto and M. Yamamoto, "Circularly polarization radial line slot antennas," IEICE Tech. Rep., AP80-57, Aug. 1980.

[2] J. Takada, M. Ando and N. Goto, "The bandwidth and the gain of radial line slot antennas with uniform slot density," IEICE Trans. Electron., vol.E73, no.8, pp.1372-1377, Aug. 1990.

[3] S. Kobayashi, K. Sudo, J. Hirokawa and M. Ando, "Efficiency of millimeter-wave band radial line slot antennas," IEICE Tech. Rep., AP2003-150, RCS2003-156, pp.27-32, Nov. 2003.

[4] Y. Kamata, O. Amano, M. Ando, H. Ueda and K. Kawahara, "A study on high gain slot array antenna fed by radial line for venus probe," IEICE Society Conference, B-1-50, Sep. 2006.
[5] H. Ueda, K. Sudo, J. Hirokawa and M. Ando, "Analysis of slot coupling in radial waveguide filled with triple-layer dielectric," IEICE Society Conference, B-1-105, Sep. 2005
[6] K. Sudo, J. Hirokawa and M. Ando, "Analysis of a slot pair coupling on a radial line filled with double-layer dielectric," IEEE AP-S, P65.8, vol.3A, pp.724-727, Jul. 2005.
[7] M. Takahashi, J. Takada, M. Ando and N. Goto, "Aperture illumination control in radial line slot antennas," IEICE Trans Commun., vol.E76-B, pp.777-783, Jul. 1993.
[8] M. Zhang, T. Hirano, J. Hirokawa and M. Ando, "Analysis of a waveguide with a round-ended wide straight slot by the method of moments using numerical-eigenmode basis functions," IEICE Trans Commun., vol.E87-B, No.8, pp.2319-2326, Aug. 2004.