Dual Circularly Polarized Concentric Array Radial Line Slot Antenna fed by Rotating modes from Front and Back Sides for Satellite Application

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1. Introduction

Radial line slot antennas (RLSAs) are well known as high-efficiency planar antennas in high-gain region for the circular polarization [1]. Figure 1 shows the structure of a general RLSA. A radial waveguide is composed of two parallel circular metal plates. An electromagnetic power is fed from the center and excites a slot array on the top plate. To obtain a pencil beam, the radiating elements are arranged spirally for in-phase excitation. Originally, RLSAs are designed for DBS reception around the frequency range of 12 GHz band. Recently, a lightweight and low profile RLSA is practically used on a Venus climate orbiter AKATSUKI [2] using a honeycomb structure in the radial waveguide as shown in Fig. 2 [3]. AKATSUKI was launched in May 2010 from Japan.

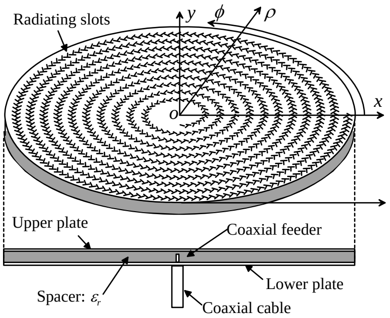


Figure 1: Structure of general RLSA

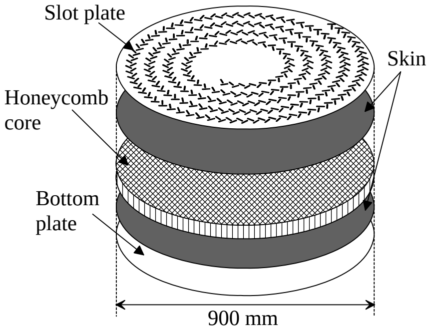


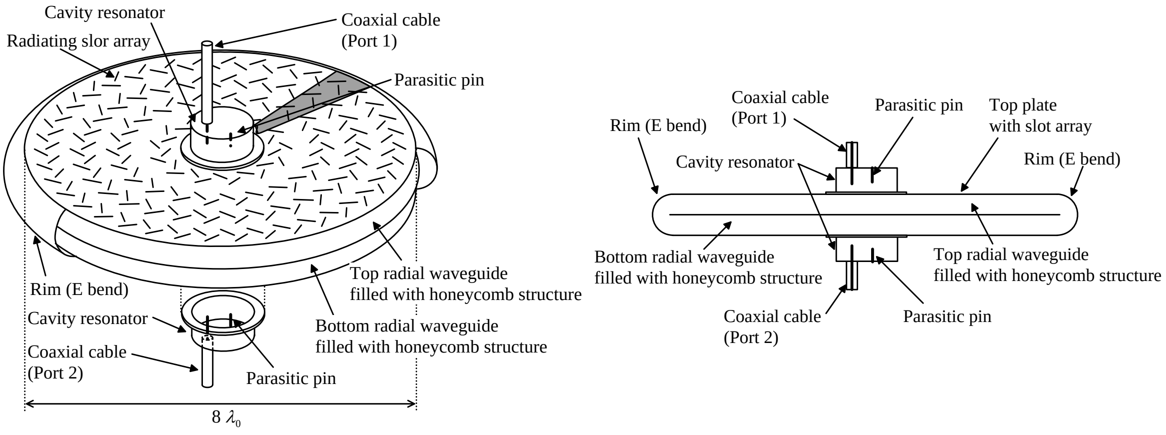
Figure 2: Structure of honeycomb RLSA

As an expansion in the range of honeycomb RLSAs for satellite applications, a dual circularly polarized (DCP-) RLSA is proposed for an enhancement of the spectral efficiency. Previously, a DCP-RLSA is investigated with a spiral array and a double coaxial feed [4]. In the previous work, since the aperture is quite large, the slot array is designed considering a continuous wave source in the radial (ρ-) direction.

Figure 3 shows the structure of the proposed DCP-RLSA. The top and bottom waveguides have exactly same structure of the honeycomb RLSA in Fig. 2 [3]. One of the discriminative points is that a concentric array is adopted for an effective utilization of the small aperture with the diameter of 8 λ_0 [5]. The other point is that the proposed DCP-RLSA is fed from its front side (port 1) and backside (port 2) as shown in Fig. 3. Cavity resonators are adopted for a rotating mode excitation [6]. The cavity resonator is designed using HFSS separately from the radiating elements. Required gain and fractional bandwidth are over 20 dBi and 5 % with the diameter of 8 λ_0. XPD of 30 dB is desired.

When the top port 1 is excited, an electromagnetic wave propagates outwardly in the top waveguide and excites the elements to radiate the right-handed circular polarization. Phase variation of $e^{-j\phi}$ is necessary to excite the array in phase in the circumferential (ϕ-) direction. On the other hands, when the bottom port 2 is excited, an electromagnetic wave propagates outwardly in the bottom waveguide at first. The wave is converted to an inward wave through the E bend. The inward wave excites the elements for the left-handed circular polarization. Phase variation of $e^{+j\phi}$ is necessary to excite the array in phase in the ϕ-direction.

In this report, a slot design method and predicted antenna characteristics are presented. Measured results of a first prototype, prospects from a comparison between the prediction and the measurement and future works are also explained.



(a) Air view (b) Cross section view

Figure 3: Structure of proposed dual circularly polarized RLSA

2. Slot array design and predicted antenna characteristics

The slot array is designed by a method of moments (MoM) [7]. The analysis model is shown in Fig. 4. A gray sectorial part in Fig. 3-(a) is extracted and approximated as a rectangular waveguide with periodic boundaries on the narrow walls. In a practical sense of the slot design, it is considered that the electromagnetic wave becomes weak along the radial (ρ-) direction.

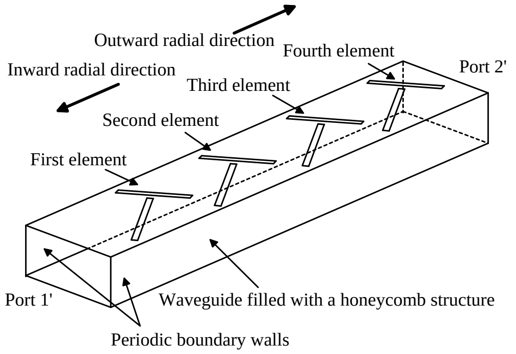


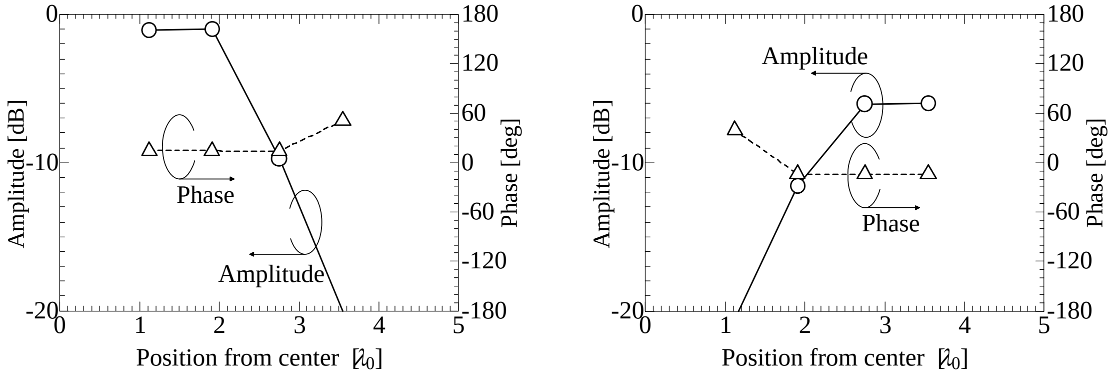
Figure 4: One-dimensional array along radial direction.

In this work, since the diameter is not large enough to use a continuous wave source, every slot parameter is designed discretely. Radiation efficiency is also taken into account because of a few elements. For high radiation efficiency, less than –20 dB is required for each S-parameter ($S_{1'1'}$, $S_{2'1'}$, $S_{1'2'}$ and $S_{2'2'}$). In Fig. 4, the port 1' (2') is correspond to the top (bottom) port 1 (2) in Fig. 3 or the outward (inward) wave.

In consequence, four turns of elements are designed as shown in Fig. 3-(a). Calculated radiating amplitude and phase in the ρ-direction are shown in Fig. 5. When the one-dimensional array is fed from port 1', the inner 3 elements are operated in phase as shown in Fig. 5-(a). In case of port 2', the outer 3 elements are in phase as Fig. 5-(b). For both cases, the reflections ($S_{1'1'}$ and $S_{2'2'}$) are below –30 dB and the transmissions ($S_{1'2'}$ and $S_{2'1'}$) are around –20 dB. At last, the designed one-dimensional array is arranged concentrically on the radial waveguide.

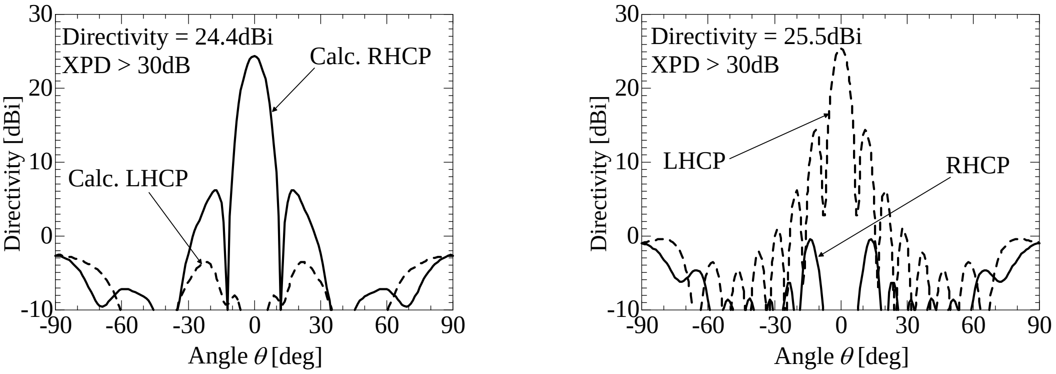
Radiation patterns are calculated using the one-dimensional distributions in Fig. 5 assuming ideal excitations ($e^{-j\phi}$ or $e^{+j\phi}$) in the ϕ-direction. A half-free space is assumed as an external region for ignoring the effect of the top feeding structure. For both excitations, the directivities are over 20dBi and the XPDs are over 30 dB as shown in Fig. 6-(a) and -(b).

Figure 7 shows frequency dependences of calculated directivities under the condition of ideal excitations in the ϕ-direction ($e^{-j\phi}$ or $e^{+j\phi}$) as well as the calculated radiation patterns. In the required fractional bandwidth of 5 %, the directivities are over 20 dBi and the specification is satisfied although the center frequency is shift by about 1.5 % lower.

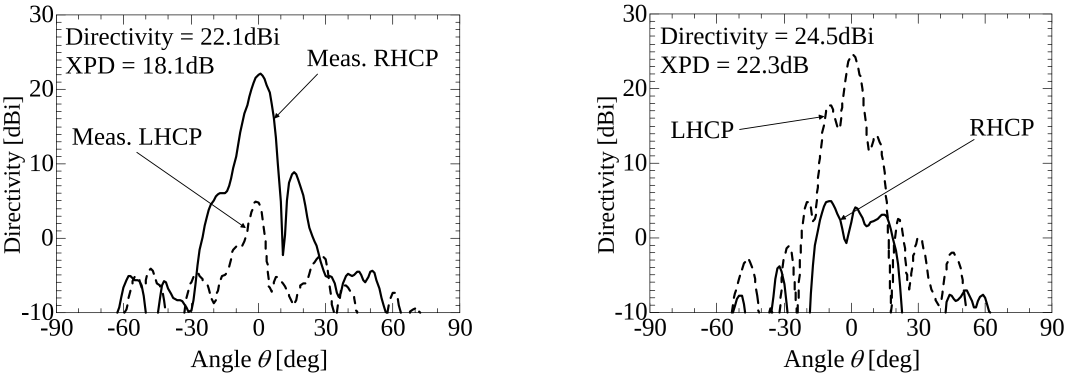


(a) Fed from port 1’ (b) Fed from port 2’

Figure 5: Calculated radiating amplitude and phase of designed one-dimensional array

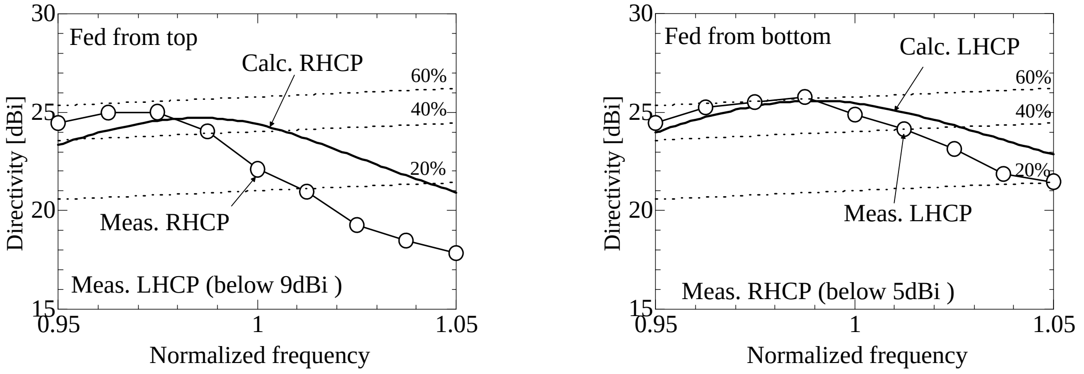


(a) Calculation (Port 1’, Outward rotating mode) (b) Calculation (Port 2’, Inward rotating mode)



(c) Measurement (Port 1, Outward rotating mode) (d) Measurement (Port 2, Inward rotating mode)

Figure 6: Radiation patterns of directivity at design frequency



(a) Fed from port 1 (Outward rotating mode) (b) Fed from port 2 (Inward rotating mode)

Figure 7: Frequency dependence of directivity

4. Measured antenna characteristics

A first prototype of the DCP-RLSA is fabricated and its near-field is measured. The near-fields are converted to radiation patterns and directivities in Fig. 6-(c), -(d) and Fig. 7.

When the top port 1 is excited, the beam shape in Fig. 6-(c) tolerably agrees with the calculation in Fig. 6-(a) but some nulls disappear. Additionally, cross polarization makes a beam at the broadside instead of a null and the XPD is declining to 18.1 dB at the design frequency. The directivity is reduced to 22.1 dBi from the calculated one of 24.4 dBi because of frequency shift as explained next. In Figure 7-(a), the directivity over 20 dBi is obtained in the desired fractional bandwidth of 5 % though there is a frequency shift to lower from the calculation.

On the other hands, in the case of the bottom port 2, the measured radiation pattern is agrees with the calculated one while some nulls disappear as well as the case of the port 1. The directivity is reduced to 24.5 dBi from the calculated one of 25.5 dBi. The frequency dependence of the directivity agrees well with the calculation and the XPD is over 20dB in the desired bandwidth though there is a little frequency shift to lower.

5. Conclusion and future works

A DCP-RLSA filled with lightweight honeycomb structures is designed and fabricated. Calculated antenna characteristics satisfy the desired specifications. In the measurement, in the both polarizations, the frequency dependences of the directivities satisfy the specification of over 20 dBi in the fractional bandwidth of 5 % though the center frequency shifts to lower by around 3 % and 1 %, respectively. The measured XPDs of the both polarizations are around 20 dB and still lower than the specification.

As future works, the center frequency has to be tuned in the design. To improve the XPDs, it is important to clarify the contributions to the degradations of the directivity, the XPDs and the frequency shift. The followings are thought of as conceivable contributions.

- ✓ The top feeding structure affects the radiation characteristic.
- ✓ Degradation of cross polarization discrimination for each element.
- ✓ Quality of the rotating mode from the designed feeding structure.
- ✓ Radiation of the cross polarization by reflecting waves in the DCP-RLSA.

References

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