Design of a linearly-polarized radial line slot antenna with reflection-cancelling posts

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1. Introduction

A radial line slot antenna (RLSA) [1] is a slot array planar antenna. Generally, the RLSA is good for circular polarization where two orthogonal slots are spaced by a quarter guided wavelength as radiating unit and excited with equal amplitude and 90-degree phase difference, so that reflection from the two slots are cancelled out. Furthermore since the radiating units are arranged sequentially, very low reflection is realized at the feeding point. On the other hands, in the linearly-polarized (LP) RLSA [2], the linear polarization in the x-direction is obtained by the spacing of a half guided wavelength ($d=\lambda_g/2$) in the radial (ρ-) direction for alternative-phase excitation between two orthogonal slots as radiating unit. Since the slot pairs are arranged concentrically with the spacing of one guided wavelength, the reflecting waves are summed up in phase at the feeding point. Reflection cancellation is one of the most important assignments for the LP-RLSAs.

To reduce the reflection, various methods have been investigated such as additional slot sets [3], beam-tilting design [4] and reflection-cancelling slots on the bottom plate [5]. However, each method has a problem such as complicated slot configuration, undesired radiation or beam tilt. We propose a LP-RLSA with a reflection cancelling post for each unit in the radial line. There is no beam tilt and no undesired radiation. In this paper, design procedure of the LP-RLSA and measured antenna characteristics of a prototype are shown.

2. Structure of LP-RLSA

Figure 1 shows the structure of the proposed LP-RLSA. A radial line is filled with double-layered dielectric. The upper layer is a forming material with the relative permittivity of $\varepsilon_r=1.08$ and the thickness of 2.0mm. The lower layer is a PTFE substrate with the relative permittivity of $\varepsilon_r=2.17$ and the thickness of 1.2mm. Reflection canceling posts with patches are fabricated in the lower PTFE substrate. Changing the patch radius, the reflection cancelling effect is controlled. In terms of travelling wave excitation, it is necessary to suppress the reflection in each unit which consists of two orthogonal slots and a post with a patch. It is enough to design a half of the slot array from $\phi=0$ to 180 degrees because of its symmetrical structure with respect to the x-axis.

3. Unit design

In Fig. 1, the gray sectoral part is extracted and approximated as one-dimensional array on a rectangular waveguide in the ρ-direction with periodic boundaries on the narrow walls. The unit shown in Fig. 2 is extracted from the one dimensional array and analyzed by HFSS. The design frequency is 22GHz. The post radius is 0.6mm.The parameters of the unit are the slot length, the slot angle, the slot positions, the post position and the patch radius. The slot length and positions are determined to realize a required radiating power and to be excited in alternative-phase between the two slots in the unit. The post position and the patch radius are for minimizing the reflection.

As an example of the unit design, reflection and radiation characteristics at 22GHz are shown in Fig. 3. The horizontal axis is the slot length in the unit which has been designed. The reflection is reduced in comparison with the original slot pair without the post. The radiation power increases by placing the post, and the maximum value also increases from 44.0% without the post to 56.1% with the post. It is confirmed that the reflection is suppressed below -40dB and the radiation power over 50% can be obtained for the other models with different ϕ.

To realize required aperture distribution, the units are arrayed in the ρ-direction. The one-dimensional array should be designed by considering the power spread in the outward cylindrical wave propagation. Since the orientation of the slots varies depending on their angle ϕ in the circumferential direction, the one-dimensional arrays are designed discretely for ϕ=0, 45, 90, 135 and 180 degrees. The ϕ–dependence on the slot parameters are interpolated. The design procedure is as follows.

Step1: Considering a continuous wave source, the radiation power distribution for the units in the ρ-direction is determined to realize the uniform aperture distribution in Fig. 4(a).

Step2: The slot parameters are obtained from the desired radiating power for each unit in Fig. 4(b)(c) and the post parameters are obtained in Fig. 4(d)(e).

Step 3: The pair spacing is adjusted so that adjacent units are excited in phase.

In consequence, eight pairs are arrayed in the ρ-direction for 100mm radius. The reflection in the one-dimensional array for ϕ= 90 degrees is shown in Fig. 5. It is suppressed to below -14.5dB. Since all the units are excited in phase, the reflections from all the units are maximized at 22.0GHz.

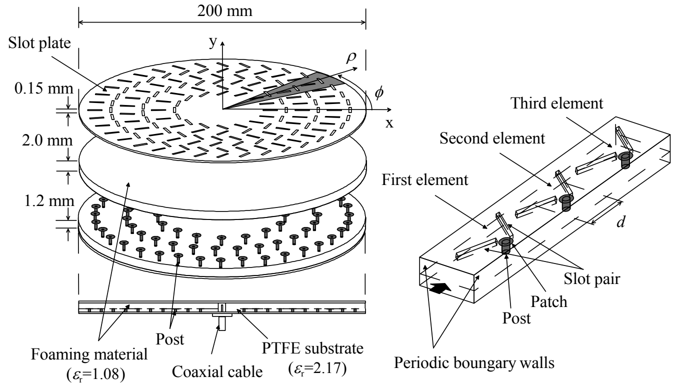


Figure 1: Structure of the proposed LP-RLSA

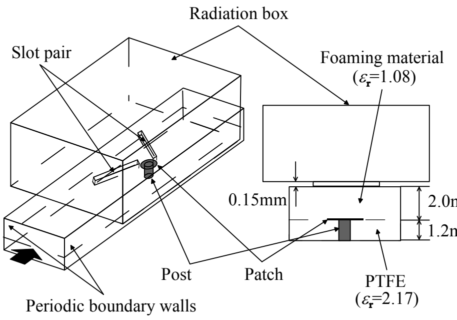


Figure 2: Analysis model of the unit (ϕ = 45°)

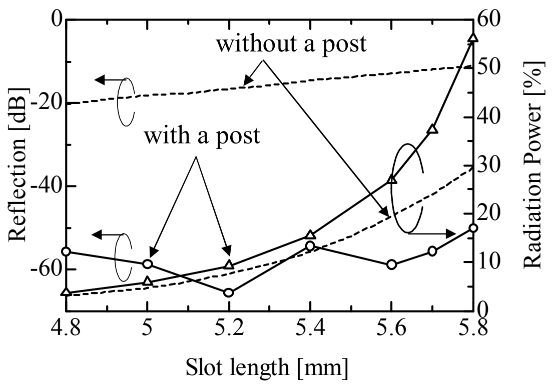


Figure 3: Reflection and radiation power in the unit design (ϕ = 90°, 22.0GHz)

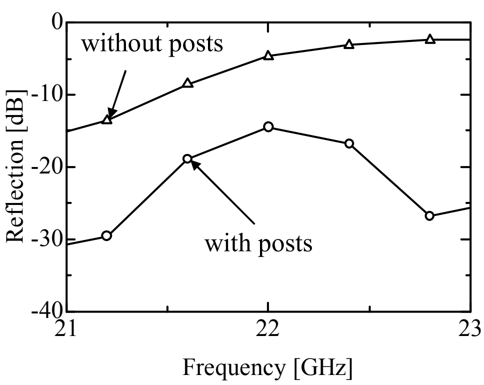


Figure 5: Reflection in the one-dimensional array for ϕ = 90°

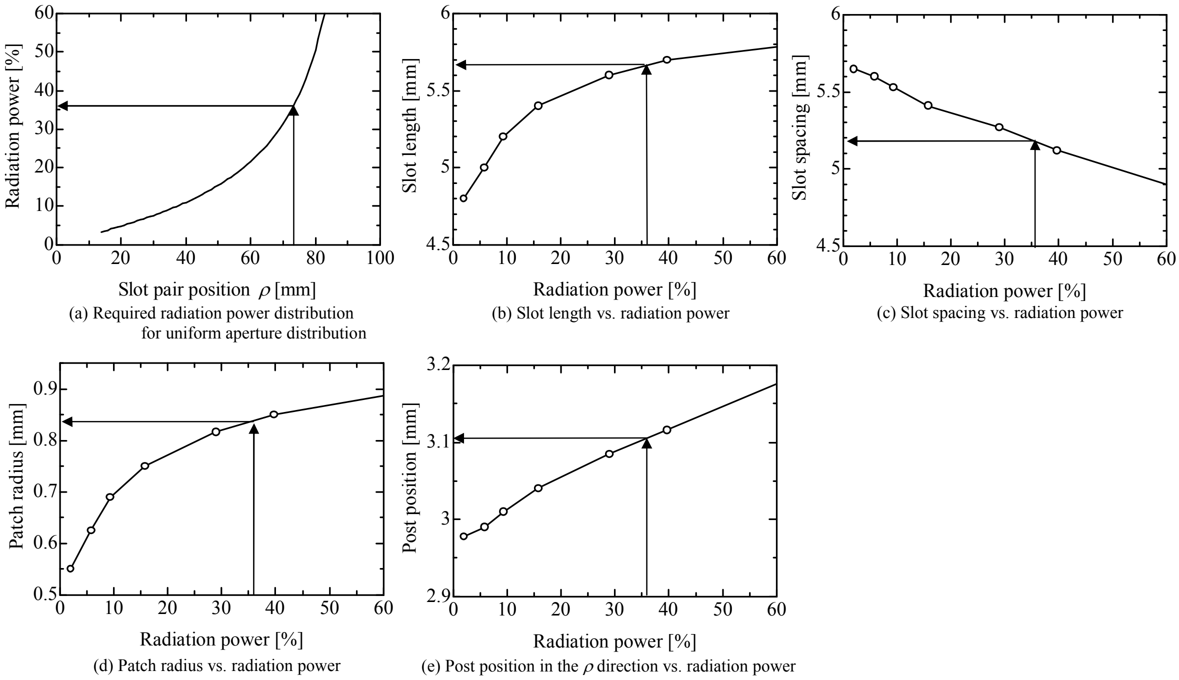


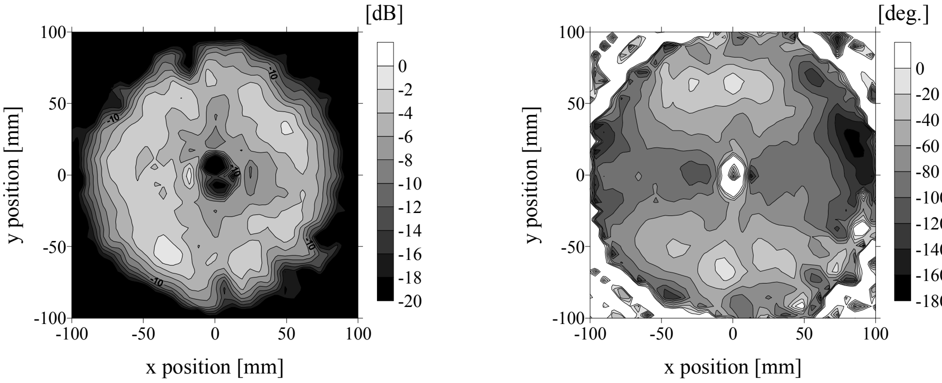
Figure 4: Parameters as functions of the radiation power for $\phi = 90°$

4. Measurement

A prototype of the LP-RLSA is fabricated and the antenna characteristics are measured. Figure 6 shows the aperture distribution at 22.0GHz where the maximum directivity is obtained. The deviation of the amplitude and the phase is 7.2dB and 74.5 degrees in the ϕ-direction and 14.9dB and 75.2 degrees in the ρ-direction, respectively. These undesired amplitude and phase deviation causes gain reduction. The radiation patterns calculated by the near-field distribution at 22.0GHz are shown in Fig. 7. The cross polarization is suppressed to -26.9 dB in the xz- plane and -24.7 dB in the yz- plane.The sidelobe level is −13.1 dB in the xz- plane and −10.8 dB in the yz-plane. Figure 8 shows the gain and the directivity. The directivity is calculated by the near-field distribution while the gain is measured by comparing a standard horn at an anechoic chamber. The maximum directivity is 30.9dBi at 22.0GHz. The maximum gain is 30.9dBi at 21.8GHz with efficiency of 59.0%.The frequency characteristic of the gain agrees with the directivity. Figure 9 shows the measured reflections of the antenna with and without the reflection cancelling posts. Additionally, the reflection at the feeding point is extracted by time-gating and suppressed below -20dB over the bandwidth from 21.0GHz to 23.0GHz. The overall reflection is suppressed from −2.4dB without the posts to −9.9dB with the posts.

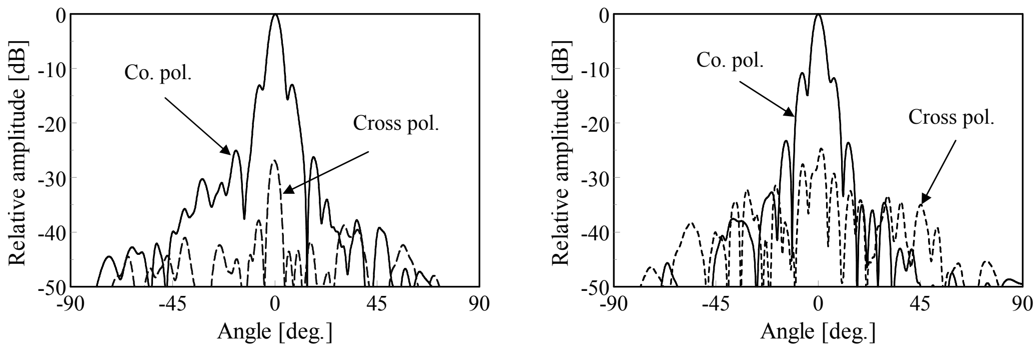
5. Conclusion

We have designed the LP-RLSA with the reflection canceling posts at 22.0GHz with the diameter of 200mm. The reflection of the unit is reduced to -40dB by properly choosing the slot and the post parameters for various radiating power. In the measurement, the gain of 30.9dBi and the efficiency of 59.0% are obtained at 21.8GHz.



(a) Amplitude (b) Phase

Figure 6: Aperture distribution at 22.0 GHz



(a) xz-plane (b) yz-plane

Figure 7: Radiation pattern at 22.0GHz

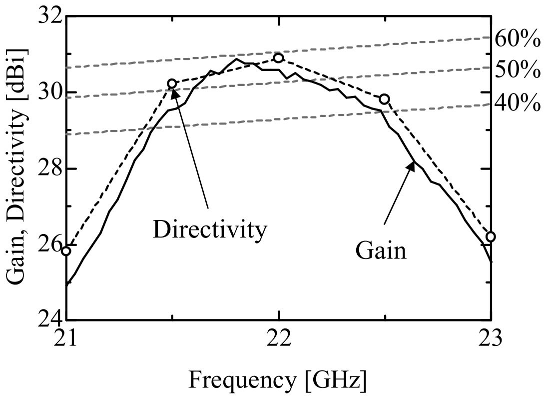


Figure 8: Gain and directivity

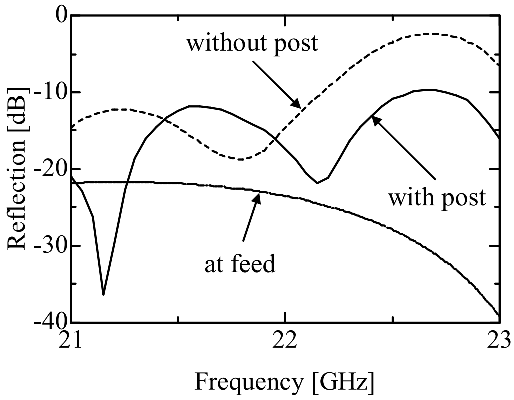


Figure 9: Reflection

References

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