Full-Model Analysis of a Radial Line Slot Antenna and Efficiency Assessment as Functions of Slot Pair Design

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Abstract- **A full-model structure of CA-RLSA with feeder has been analyzed by using the MoM. The results of the calculated aperture-field show reasonable agreement with the experimental ones on the outermost round of slot pairs by the full-model analysis. We estimate effect of distance between slot pairs in ϕ-direction. As a result of design, enhance of the aperture efficiency is 2%. We propose a design method by using this full-model analysis. The ρ-positions of the slot pairs are adjusted respectively to suppress the deviation of the phase in the ϕ–direction. As a result of calculation in the 22 GHz band, dielectric constant ε_r=2.2, height h=3.2 mm, the three kind of parameters are determined as the aperture efficiency is high.**

I. 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 at 12 GHz band [1]. The slot design for realizing uniform aperture illumination and maximizing antenna efficiency is the key feature of RLSAs. A rotating mode which is uniform in amplitude and linearly tapered in phase in the circumferential (ϕ–) direction in a radial waveguide together with concentric arrangement of the slot pairs is required to get a pencil-beam in the boresight in a concentrical-array RLSA (CA-RLSA) [2]. The antenna characteristics of CA-RLSA have been estimated based upon the assumption of ideal rotational symmetry, by using a linear array model of slot pairs in a rectangular waveguide with periodic-boundary walls [3] as is shown in Fig. 2. Since an actual feeder to excite the rotating mode for CA-RLSA is not symmetrical in the ϕ–direction, the measured efficiency of CA-RLSA is lower than the calculated one [2,4,5]. The degradation of the aperture efficiency with the rotational asymmetry into account, can not be estimated in principle, in the above-mentioned linear array model.

In this paper, a structure of CA-RLSA including the feeder is analyzed numerically by the method of moments (MoM). We call hereafter this analysis as ``full-model analysis''. Figure 1 shows the structure of the antenna with the feeder. The broad wall of a rectangular waveguide is connected to the center of the lower plate of a radial waveguide. The radial waveguide is excited through a crossed slot. A RLSA with this feeder was designed and fabricated at 5.8 GHz. The gain of an antenna with the diameter of 300 mm was 22.7 dBi with efficiency of 56 % [5]. In this paper, the calculated results by the full-model analysis are compared to the measurement results. The three parameters of slot pairs are estimated by using the full-model analysis.

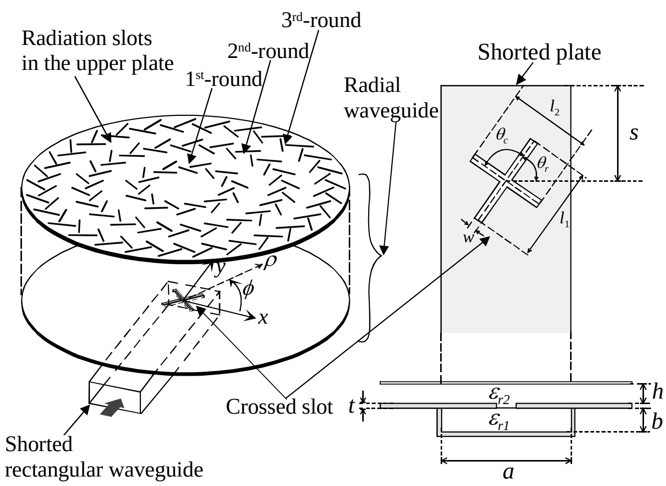

Fig. 1. Structure of CA-RLSA fed by a rectangular waveguide.

II. ANALYSIS MODEL

Figure 3 shows the analysis model of CA-RLSA including the feeder. We use the eigenmode functions of the electric field determined by the cross section of the crossed slot as the basis functions of the equivalent magnetic currents [7]. The region of the radial waveguide can be replaced with an equivalent model where the original magnetic currents and their images spacings due to the parallel plates exist in free space [8].

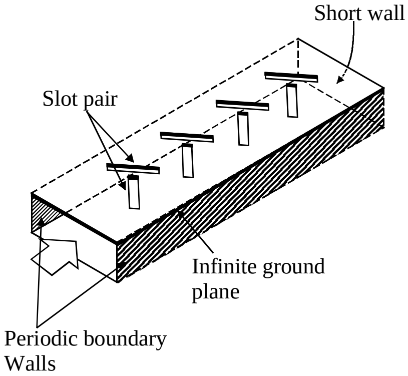

Fig. 2. Linear array model.（Conventional）

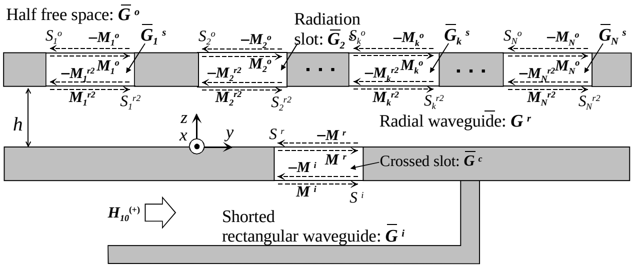

Fig. 3. Full-model for MoM analysis.

III. CALCULATED RESULTS

We calculate the model of CA-RLSA fed by a rectangular waveguide in the 5.8 GHz band and compare to the measurement results. Figure 4 shows the calculated and measured aperture distribution over the radial waveguide at 5.8 GHz. The calculated aperture-field distribution is the excitation of each slot pairs on the outermost round by the full model analysis. The calculated ripple of the amplitude and the deviation of the phase in the ϕ–direction are about 5.3 dB and 33 degrees (peak to peak) in the aperture field. The calculated results show reasonable agreement with the experimental ones. To see the detail of the slot perturbation, the inner-field distribution in the radial waveguide without any radiation slots is also measured, calculated and included in Fig. 4. The ripple of the amplitude in the inner-field without slot perturbation is suppressed to 3.0 dB[5] both in measured and calculation. Then, the ripple of the aperture field is considerably larger than that of the inner-field distribution because of the perturbation of the slot array on the upper plate. The full model analysis accurately predicts the effects of this perturbation.

Figure 5 shows the calculated directivity of the antenna in the 5.8 GHz band. In the full-model analysis, the directivity at the design frequency is 22.7 dBi and the efficiency is 55.5%. For, this specific model, the efficiency predicted by the full model is only 0.4% lower than that by conventional model using the linear array based upon the assumption of rotational symmetry. The degradation of the efficiency by the azimuth at amplitude ripple of 3.0 dB is estimated to be small.

IV. ESTIMATION OF THE EFFCTS OF SLOT PAIR PARAMETERS UPON EFFECIENCY

We estimate effect of three parameters of slot pairs by using the full-model analysis. Three parameters are shown in Fig. 6 and as follows:

1. Distance of each slot pair in ϕ–direction $\boldsymbol{d_\phi}$
2. Distance of each slot in ϕ–direction $\boldsymbol{p}$
3. Radius of 1st round slot pairs $\boldsymbol{\rho_b}$

These parameters affect the quality of azimuthal symmetry and therefore can not be optimized by using the linear-array model. We design the CA-RLSA fed by a rectangular waveguide in the 22 GHz band. The height of the radial waveguide is 3.2 mm and relative dielectric constant ε_r is 2.2. The aperture has five rounds of slot pairs. Model 1 (d_ϕ=0.6λ, p=0.26λ, ρ_b=1.0λ) in Table 1 is best designed one in changing the three parameters. Model 2 and 3 are changed the d_ϕ, model 4 and 5 are changed the p, model 6 and 7 are changed the ρ_b. The slot arrangements are shown in Fig. 7. These parameters are normalized by wavelength λ including ε_r of the radial waveguide.

Figure 8 shows the aperture efficiency for the change in the parameter d_ϕ. The aperture area is defined by the edge of outermost slot. The peak of calculated aperture efficiency is 87% in d_ϕ=0.60λ. When the d_ϕ is smaller than 0.6λ, the efficiency decreases. The calculated azimuthal amplitude ripples of the aperture distributions, observed on the fourth slot pair round, for d_ϕ=0.50λ, 0.60λ, and 0.80λ are 4.2 dB, 4.9 dB, and 18.2 dB, respectively. As the ripple in ϕ–direction becomes larger for wider d_ϕ, the efficiency becomes low.

The aperture efficiency for the change in the parameter p is shown in Fig. 9. This parameter has small effect on the aperture efficiency. The variation width of the directivity is only 0.2 dBi.

Figure 10 shows the aperture efficiency for the change in the parameter ρ_b. When the ρ_b is too small, the efficiency falls by about 20%, since the effect of the mutual coupling between the radiation slots and crossed slot is large. The efficiency takes its peak at ρ_b =1.0λ, and when the ρ_b becomes over 1.0λ, the aperture efficiency decreases by effect of blocking space.

We estimated the effect by changing the d_ϕ , p and ρ_b , and the aperture efficiency is changed over 20%.

V. CONCLUSIONS

A full model structure of CA-RLSA with feeder has been analyzed by using the MoM. The results of the calculated aperture-field show reasonable agreement with the experimental ones on the outermost round of slot pairs by the full-model analysis. We estimate the effects of slot design parameters upon the antenna efficiency. As a result of design in the 22 GHz band, the calculated aperture efficiency is 87% in d_ϕ=0.6λ, p=0.26λ, ρ_b=1.0λ.

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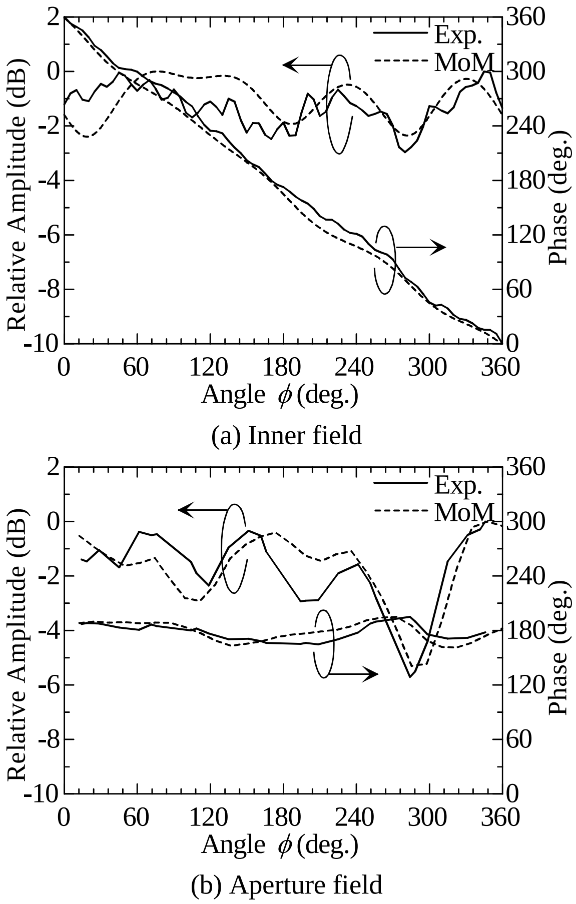

Fig. 4. Aperture and inner field distribution in radial waveguide (5.8 GHz).

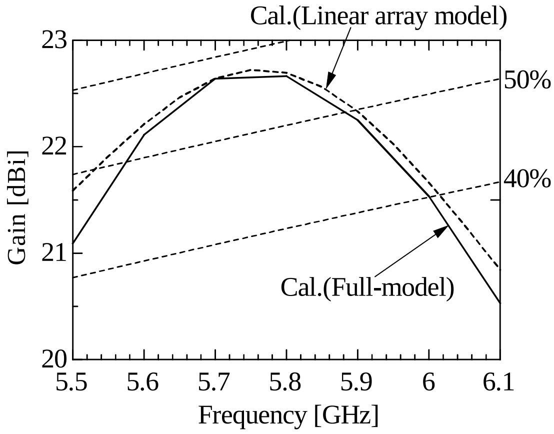

Fig. 5. Calculated directivity of CA-RLSA.

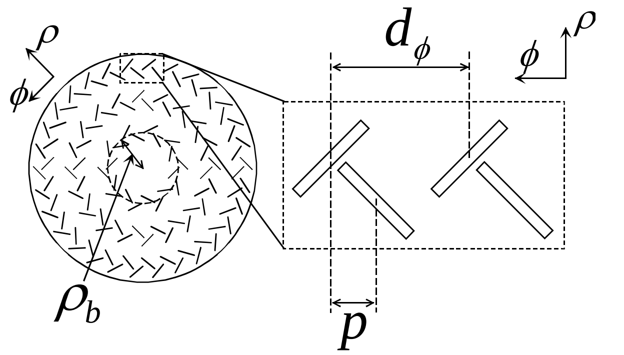

Fig. 6. Three kinds of parameters in each slot pair

Tab. 1. Value of the parameters in seven models.

	$d_\phi(\lambda)$	$p(\lambda)$	$\rho_b(\lambda)$
Model 1	0.6	0.26	1.0
Model 2	**0.5**	0.26	1.0
Model 3	**0.8**	0.26	1.0
Model 4	0.6	**0.22**	1.0
Model 5	0.6	**0.35**	1.0
Model 6	0.6	0.26	**0.3**
Model 7	0.6	0.26	**1.6**

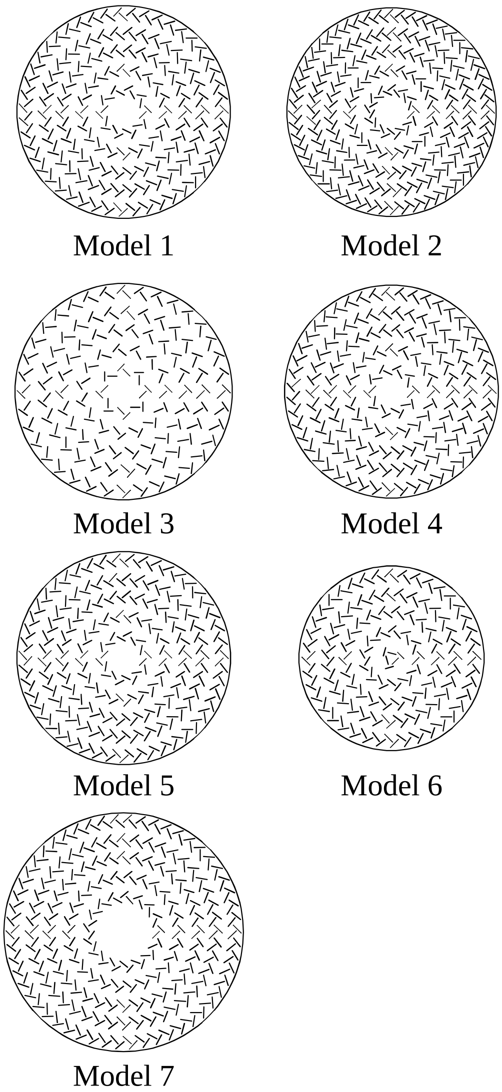

Fig. 7. Slot arrangements of CA-RLSA.

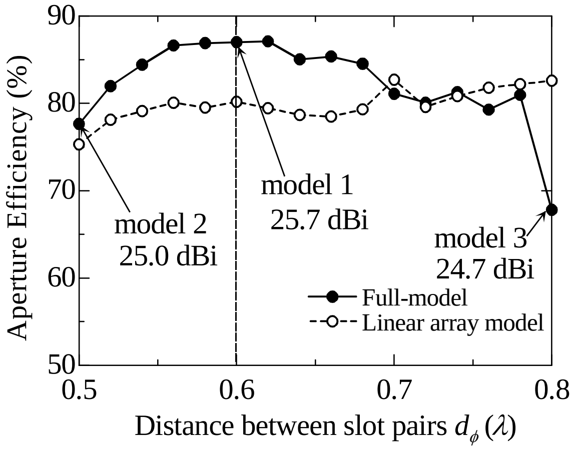

Fig. 8. Calculated aperture efficiency by changing d_ϕ.

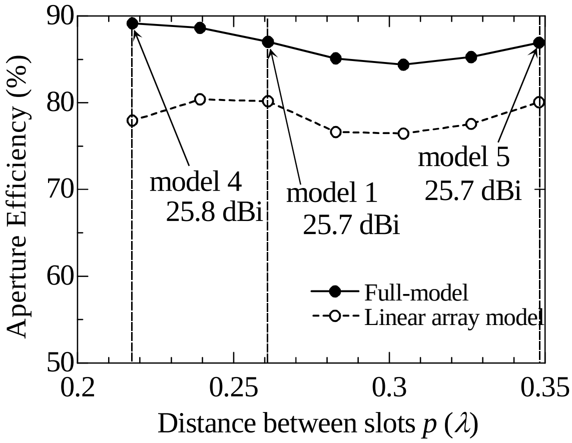

Fig. 9. Calculated aperture efficiency by changing p .

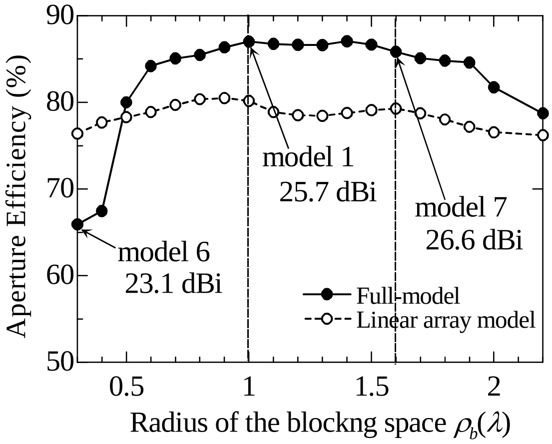

Fig. 10. Calculated aperture efficiency by changing ρ_b .