A SINGLE-LAYERED CIRCULARLY-POLARIZED RADIAL LINE SLOT ANTENNA

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1. INTRODUCTION

A radial line slot antenna (RLSA) is a kind of slotted waveguide array for DBS reception [1][2]. It is free of conductor loss and the aperture efficiency is more than 75%, twice as high as conventional planar antennas [3]. Those performances have been realized for double-layered RLSAs with uniform slot length.

This paper presents a design of single-layered RLSA. Key technologies are non-uniform slot arrangement for uniform aperture field distribution and a matching spiral in place of a absorber at the terminal. The equivalent S-parameters for a slot pair obtained by the full wave analysis are used in aperture synthesis. The matching spiral suppresses the reflection and radiates all the residual power in desired polarization. The design is verified by experiment. The gain of 35.4 dBi / aperture efficiency of 65 % is measured for 60cmϕ model antenna.

2. A SINGLE-LAYERED RLSA

Figure 1 shows a single-layered RLSA [4]. On the top plate, a lot of slots are arranged to radiate the circular-polarization. Two slots form a slot pair as a unit radiator of circular-polarization. The pairs are arranged spirally with pitch S_ρ equal to the guide-wavelength λ_g and are excited in phase by a radially outward traveling wave.

The difficulties in this structure compared with the double-layered one are followings:

i) The attenuation of outward traveling wave and the attenuation due to slot coupling results in steeply tapered aperture field if uniform slot length and distribution are adopted (Fig.7(a)).

ii) The increase of termination loss reduces the efficiency and increases the thermal noise, which results in C/N degradation.

3. SLOT DESIGN

The problem i) is solved by controlling the slot coupling. Slot length as well as its spacing is varied over the aperture to realize the uniform aperture field distribution. The flow-chart of design procedure is shown in Fig.2.

Full-wave analysis

A periodic structure model (Fig.3) is applied to simulate the slot coupling to the radial waveguide in rotationally symmetric operation [5][6]. An equivalent circuit model of slot pair is introduced as shown in Fig.4. The slot pair equivalent circuit is connected at the center of transmission line (length S_ρ). In the full wave analysis, the S-matrix of the circuit is obtained together with the slot excitation coefficient. Since the slots in a pair are spaced by $\lambda_g/4$ from each other in the ρ direction, the reflection coefficient S_{11} of a slot pair is nearly zero. Therefore, $(1-|S_{21}|^2)$ denotes the strength of coupling, while $arg(S_{21})$ gives the phase variation of the inner field for S_ρ. On the other hand, the phase difference between the inner field and the slot excitation field $\Delta\phi$ is also given in the analysis. All those parameters are given as functions of slot length L.

Coupling factor and Slow wave factor

The inner field is approximately expressed by using the continuous attenuation model in Fig.5 as

$$2\pi\rho P(\rho)d-2\pi(\rho+\Delta\rho)P(\rho+\Delta\rho)d=2\pi\rho\Delta\rho\tau P(\rho) \qquad (1),$$

where $P(\rho)$ is inner power density, τ is the ratio of slot coupling strength to inner power and d is the height of guide. Now $\tau/2d$ is defined as the coupling factor $\alpha(\rho)$. To realize a uniform aperture distribution, the aperture power density $\alpha(\rho)P(\rho)$ should be constant. Imposing this upon (1), we get

$$\alpha(\rho)=\frac{\rho}{K-\rho^2}, \quad K=\frac{\rho_{MAX}^2-t\rho_{min}^2}{1-t} \qquad (2),$$

where t is the termination loss. Figure 6 shows the coupling factor $\alpha(\rho)$ as function of ρ. The factor $\alpha(\rho)$ takes its maximum value at the edge ($\rho=\rho_{MAX}$). Since the factor can not be increased arbitrarily so as not to disturb the rotational symmetry (e.g. 15 ~ 20 [1/m]), the minimum value of t is determined.

The relation between α and $|S_{21}|$ is given as

$$\alpha=\frac{1-|S_{21}|^2}{2S_\rho} \qquad (3).$$

On the other hand, slow wave factor is defined as the ratio of guide wavelength and free space wavelength as

$$\zeta=\lambda_g/\lambda_o \qquad (4).$$

The phase variation of the inner field is shown in Fig.4(c) and $\Delta\theta(L)=arg(S_{21})$ is the phase jump at slot pair. ζ is therefore given by

$$\zeta=\frac{2\pi S_\rho}{\left(\frac{2\pi S_\rho}{\lambda_o/\sqrt{\varepsilon_r}}-arg(S_{21})\right)\lambda_o} \qquad (5).$$

Aperture synthesis

With the result of full-wave analysis, slot length L is given as the function of α in Eq.(3). Substituting Eq.(2) for $L(\alpha)$, we get L as the function of position ρ (Amplitude Design). At the same time, slot radial spacing S_ρ is set equal to $\lambda_g(\rho)$ to realize

$$\theta o=\theta i+2\pi \qquad (6)$$

in Fig.4(c). The excitation phase error due to change in $\Delta\phi$

is finally compensated by perturbing the pair position in ρ direction to realize constant ϕ (Phase Design).

Figure 7 shows the measured aperture distribution of model antenna. Uniform aperture distribution, both amplitude and phase, is obtained.

4.MATCHING SPIRAL

The problem ii) is solved by adopting a matching spiral. A matching spiral is set instead of absorber to reduce the reflection from the outermost part of the guide. It radiates all the power left unradiated from slots and reduces thermal noise.

Figure 8 shows the measured and analyzed reflection of this component. The shape is numerically optimized [7] and the reflection is less than -15 dB, which is in good agreement with measured value.

The spiral pitch is set equal to λ_g to radiate circularly polarized field at the antenna boresight [1]. The slot pairs and the matching spiral should be excited in phase. Figure 9 shows the relative location of outermost slot pair and innermost part of matching spiral. The spiral mainly radiates the ρ component of electric field. Therefore, the distance δ is determined so that ρ-components of radiated field from spiral and slot pair should be in phase.

5.MEASUREMENT

Figure 10 shows the measured gain of the model antenna with diameter of 60 cm. In the design, 20 % of the energy is radiated from the matching spiral. The gain of 35.4 dBi and the aperture efficiency of 65 % is measured at 11.6 GHz. The measured gain improvement by spiral is only 0.2 dB, but larger improvement is expected for smaller antennas. It is noted that the axial ratio is around 1 dB without absorber.

6.CONCLUSION

A design of a single-layered RLSA is proposed. Key technologies are the slot coupling control and the matching spiral. The design is confirmed by experiments.

ACKNOWLEDGEMENT

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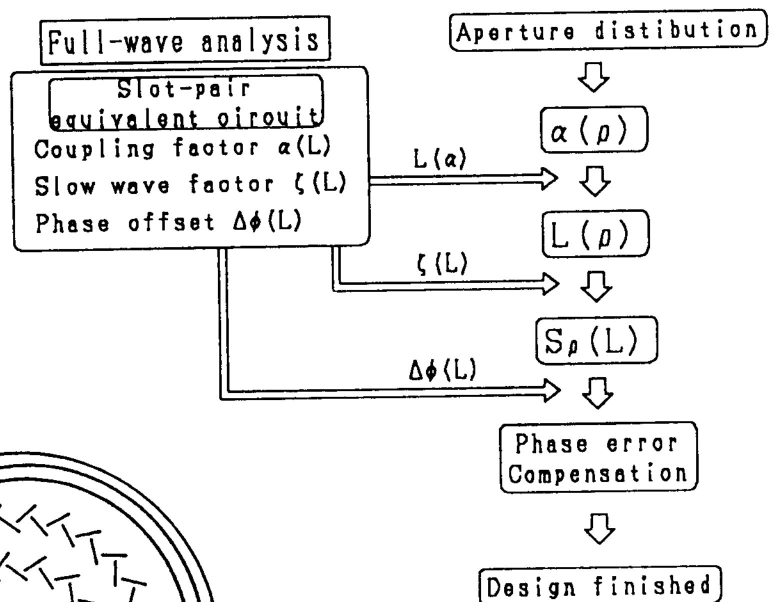

Fig.2 Flow-chart of aperture synthesis.

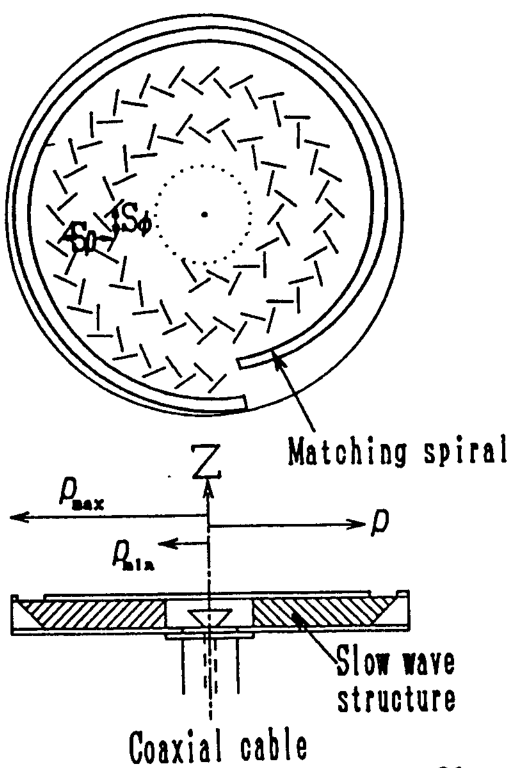

Fig.1 A single-layered RLSA.

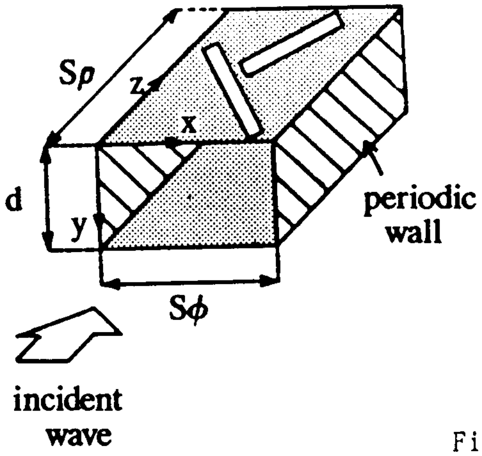

Fig.3 Analysis model.

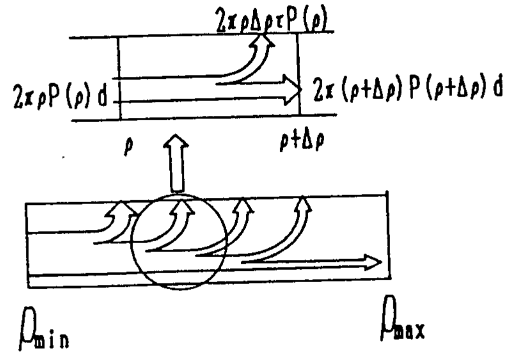

Fig.5 Continuous attenuation model in the guide.

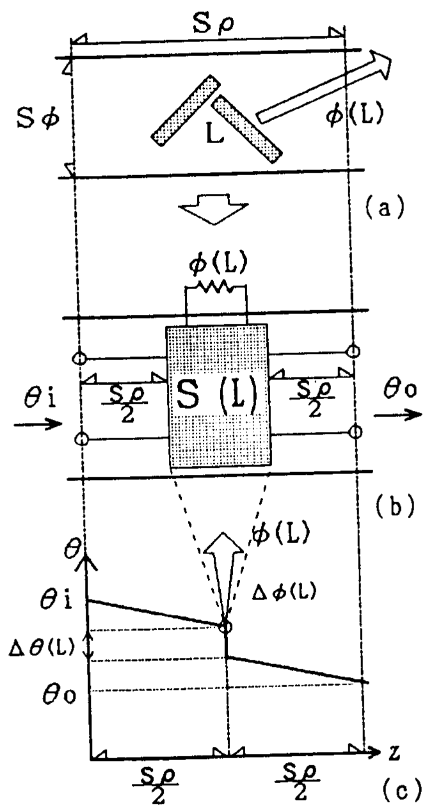

Fig.4 An equivalent circuit of a slot-pair.
(a) Configuration.
(b) Equivalent circuit.
(c) Phase distribution.

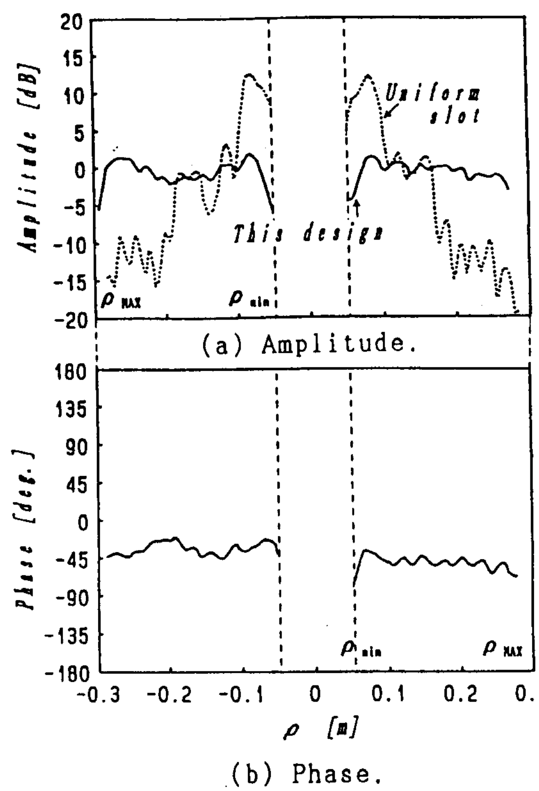

Fig.7 Measured aperture field distribution.

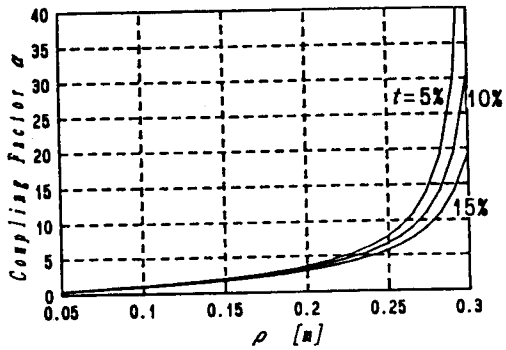

Fig.6 Coupling factor as function of location $\alpha(\rho)$.

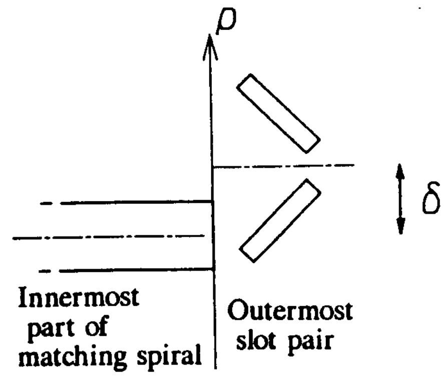

Fig.9 Relative location of slot pair and matching spiral.

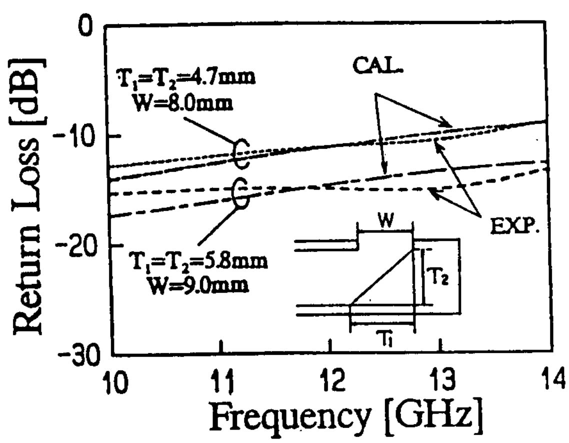

Fig.8 Reflection from a matching spiral.

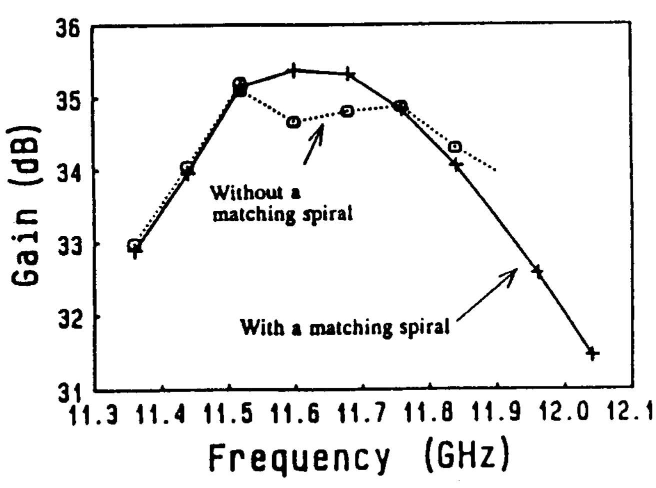

Fig.10 Measured antenna gain.

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