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FULL WAVE ANALYSIS MODELS OF SMALL APERTURE RADIAL LINE SLOT ANTENNAS

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1. Introduction

Radial line slot antennas (RLSA) are high efficiency and high gain planar waveguide antennas. RLSA is superior to other planar antennas in that it has negligible conductor loss and has extremely high efficiency in high gain range, more than 80% at 35dBi for example[1]. On the other hand, if the aperture becomes smaller, RLSA has lower efficiency mainly due to the termination loss and degraded rotational symmetry of the fields. Recently, various types of the low gain services have been developed in the mobile satellite communication and intensive works for enhancing the efficiency of small size RLSA[2] have been stimulated. This includes circularly polarized conical beam antennas for N-Star receiving and pencil beam antennas for low speed data transmission using BS channels.

Slot coupling analysis is the key technology for the antenna design. For larger arrays with many slots, RLSA have been successfully modeled using periodic boundary conditions. For extremely small RLSAs as stated above, however, slot coupling should be analyzed for the actual structure with all the slots as well as the cylindrical periphery of the waveguide taken into account. The objective of this paper is to review the full wave analysis of slot coupling in RLSA's and to propose a complete analysis model of small RLSA's.

We consider a conical beam radial line slot antenna (CB-RLSA) as is shown in Fig. 1[3]-[5] whose operation was verified numerically and experimentally[3]. Once the reliable computer code is developed, perfect numerical optimization of the antenna design would be possible, since the number of slot design parameters is small.

2. Conventional Analysis

In the conventional analysis, there are three kinds analysis models given below.

1) The plane wave incident model in the rectangular waveguide with periodic wall as is shown in Fig. 2.
In the RLSAs of the aperture of 30-60cmϕ composed of several or more turns of slot pairs, the curvature is ignored and the radial line can be replaced to the rectangular waveguide with periodic boundary walls[6]. The advantage is that the reaction between slots is solved analytically in Cartesian co-ordinates. In the small aperture RLSAs, however, the field near the aperture center can not be simulated.

2) The infinite parallel plate model as is shown in Fig. 3.
For the analysis of the slot coupling in the innermost turns of the RLSAs which is large to some extent, the infinite parallel plate waveguide model is utilized[7]. This model neglects the aperture periphery and can not be used in the design of matching slots with the outer periphery shorted.

3) The rectangular cavity model with short pins as is shown in Fig. 4.
In the very small RLSAs composed of only one slot turn, the rectangular cavity with short pins arrayed circularly is used for the method of moment analysis instead of the short wall of waveguide periphery[8]. The distance between the adjacent pins must be smaller than $\lambda/17$. Therefore, many numbers of the pins, together with mode in the cavity and basis function on the slot, must be added in

the calculation and it causes the large matrix size and computation time even for one turn RLSA.

3. Complete analysis model

3.1 Analysis model

Figure 5 shows an analysis model. Short-circuited radial waveguide, i.e., circular cavity is fed by the coaxial line at the center. A unit radiator of circular polarization, a slot pair, is composed of two perpendicular slots excited in 90° phase difference. These slots are arranged circularly and excited in axial symmetrical mode in the sense of right-hand circular polarization (RHP) along circumference to make null toward the broadside. In this structure, the circularly polarized conical radiation pattern can be radiated.

Plane wave incidence is not suitable to approximate the operation, because the distance from the center to those slots is small and cylindrical wave excitation model is inevitable.

3.2 Moment method

As is shown in Fig. 5, two conductor plates are composed of a parallel plate waveguide, the top of which is an aperture with slot pairs. An incident TEM wave propagates towards $+\rho$ direction.

In order to derive a set of integral equations, the analysis model is divided into two regions, the upper half region (region 1) and the sectorial cavity with periodic boundary walls (region 2). According to the field equivalent theorem, the continuity condition of tangential magnetic field on the i-th slot Si requires the integral relation as follow.

$$\sum_i \iint_{Si} G_{1m}[E_i \times (-\hat{z})]ds_i = H_{in} + \sum_i \iint_{Si} G_{2m}[E_i \times (-\hat{z})]ds_i \qquad (1)$$

where E_i, and $\hat{z}$ are the electric field on the i-th slot and a unit vector in z-direction, respectively. H_{in} is the incident TEM magnetic field expressed by the function below.

$$Hin = \hat{\phi}\frac{2}{\pi h}\sqrt{\frac{j\omega\varepsilon}{k_0}}\left[H_1^{(2)}(k_0\rho) - \frac{H_0^{(2)}(k_0a)}{H_0^{(1)}(k_0a)}H_1^{(1)}(k_0\rho)\right] \qquad (2)$$

where $H_1^{(1)}$, $H_1^{(2)}$ and $H_0^{(1)}$, $H_0^{(2)}$ are Hankel function of first order and of first and second kind and zeroth of first and second kind, respectively.

In eq (1), G_{1m} is a dyadic Green's function for the magnetic field produced by a unit magnetic current in region 1 and is twice as large as the free space Green's function, while G_{2m} is that for region 2. G_{2m} is expanded in the series of normal modes of the sectorial waveguide in Fig. 6. For the reduction of eq. (1) to a system of linear equation, *Galerkin's method of moments* is adopted. To this end, E_i is approximated with only one unknown coefficient A_i.. Once the coefficient for each slot is determined, the inner field perturbed by slot coupling is derived easily.

The equation (1) is multiplied with the basis functions $e_j \times \hat{z}$ and is integrated over the slot aperture Sj. A system of integral equations leads to

$$\sum_i A_i \iint_{S_j} \iint_{S_i} (e_j \times \hat{z})(G_{1m} + G_{2m})(e_i \times \hat{z})ds_i ds_j = -\iint_{S_j} (e_j \times \hat{z})H_{in}ds_j \qquad (3).$$

In this case, the Hertzian potential for *H* mode (TE mode) and *E* mode (TM mode) are listed as below.

(1) *H* mode (TE mode)

$$\psi_{hu} = \frac{p_{\nu m}}{a}\sqrt{\frac{\varepsilon_n / \pi}{p_{\nu m}'^2 - \nu^2}}\frac{J_\nu(\frac{p_{\nu m}'}{a}\rho)}{J_\nu(p_{\nu m}')}\begin{bmatrix}\cos \nu\phi \\ \sin \nu\phi\end{bmatrix} \qquad (4)$$

(2) *E* mode (TM mode)

$$\psi_{eu} = \frac{1}{a}\sqrt{\frac{\varepsilon_n}{\pi}}\frac{J_v(\frac{p_{vm}}{a}\rho)}{J_{v+1}(p_{vm})}\begin{bmatrix}\cos v\phi \\ \sin v\phi\end{bmatrix} \qquad (5)$$

where the subscript u indicates all the combinations of mode numbers m and ν $(=\frac{2\pi n}{\phi_0})$ and subscripts ε_n is normalized constant. ψ_h and ψ_e are normalized in z-direction. From those steps stated above, numerical analysis is performed.

4. Conclusion

This paper presents full wave analysis models of very small aperture RLSAs and prepares the method of moments analysis.

References

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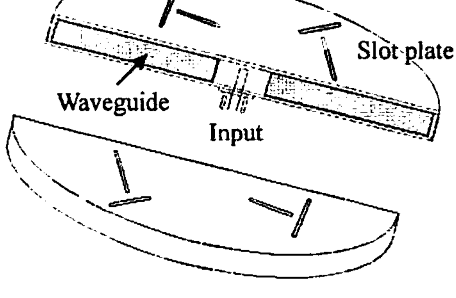

Fig. 1 CB-RLSA

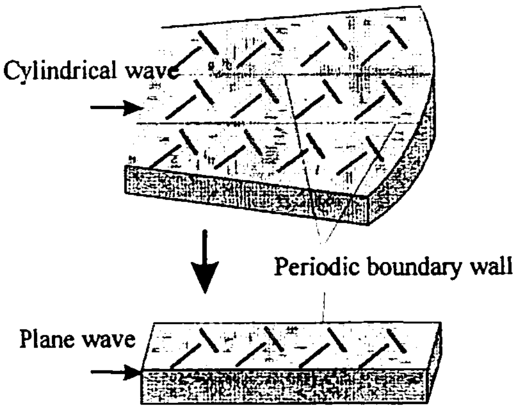

Fig. 2 Plane wave incident model

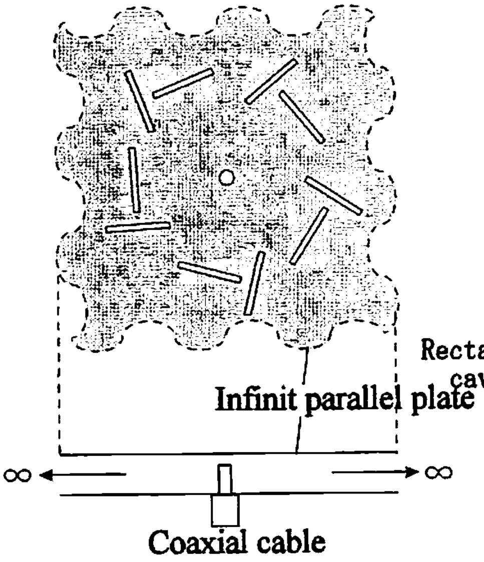

Fig. 3 Infinite parallel plate model

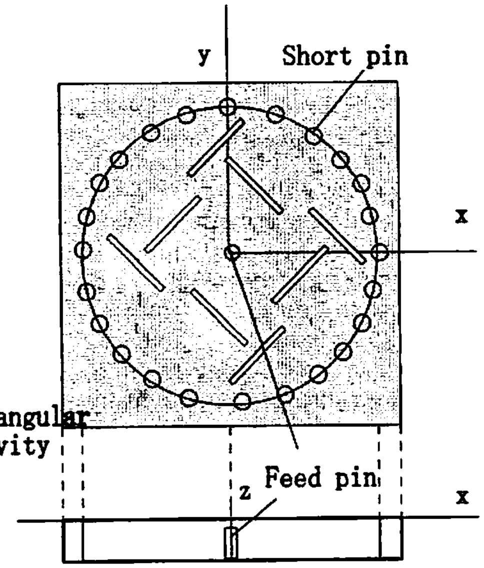

Fig. 4 Rectangular cavity model

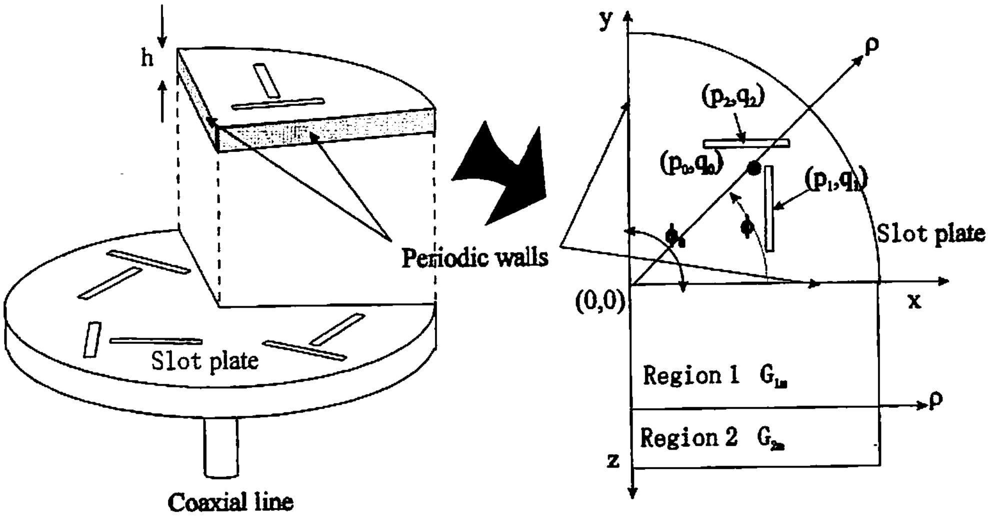

Fig. 5 Analysis model (sectorial cavity with periodic walls)