AN ANALYSIS OF SLOT COUPLING IN A RADIAL LINE SLOT ANTENNA

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1. Introduction

A radial line slot antenna (RLSA) is a planar antenna for receiving direct broadcast from a satellite (DBS) [1]. It is a kind of slotted waveguide antennas. The conductor losses are so small that high efficiency is expected in principle [2]. The measured efficiency is 75% which is about twice as high as the popular planar antennas using microstrip [3].

In the design of a RLSA, the control of the slot coupling and for realizing the desired aperture field distribution is the key technology. Up to the present, the slot coupling control is based on the measured data [4]. In this antenna, many parameters, such as the arrangement and the configuration of slots, the height of the waveguide and the permitivity of the dielectric filled in it, should be optimized. In the advanced design of this antenna, the analysis which can predict the effects of all these parameters upon the slot coupling has been strongly required.

In this paper, the model simulating the slot coupling in a RLSA is proposed. A set of integral equations is formulated and is numerically solved by the Galerkin's method. The slot coupling is predicted as functions of various design parameters. The calculated value is verified by the experiment and fine agreements are demonstrated.

2. Analysis

Figure 1 presents the construction of RLSA. Three plates compose a twofold radial line waveguide. The top plate is an aperture with slots. Electromagnetic power fed at the center of the lower waveguide through a coax-to-radial line adapter generates a radially inward traveling TEM mode in the upper waveguide, which couples to the slots. Slots are paired and are spirally arrayed so that the radiation is added in phase in the antenna broad side. In order to suppress the grating lobes from the array, the upper waveguide is filled up with expanded polyethylene as a slow wave structure.

We propose a simple simulation model to analyze a RLSA. The slot excitation by a radially traveling TEM mode in the peripheral region of the aperture should be expressed properly. Figure 2 shows the analysis model satisfying these requirements. Two infinite conductor plates spaced by b compose a parallel plate waveguide, the top of which is an aperture with slot pairs. An incident plane wave (TEM) propagates towards +z direction.

Slot pairs are arrayed infinitely in x direction; the periodic condition in x direction is imposed to derive dyadic Green's functions in the waveguide as in Fig.3. Consequently, the structure to be analyzed is the slotted rectangular waveguide along z direction, in which the field satisfies the periodic boundary conditions on its narrow walls.

To derive a set of integral equations, the analysis model is divided into two regions, which are the upper half space (region 1) and the parallel plate waveguide (region 2). According to the field equivalence theorem, he continuity condition on the i-th slot S_i requires the integral relation as below:

$$\sum_i \iint_{S_i} \mathbb{G}_1^m \cdot \{\mathbf{E}_i \times (-\hat{\mathbf{y}})\} ds_i = \mathbf{H}_{in} + \sum_i \iint_{S_i} \mathbb{G}_2^m \cdot (\mathbf{E}_i \times \hat{\mathbf{y}}) ds_i \tag{1}$$

where $\mathbf{E}_i$, $\hat{\mathbf{y}}$ and $\mathbf{H}_{in}$ are the electric field on the i-th slot, a unit vector in y direction and the incident TEM magnetic field, respectively. In eq.(1), $\mathbb{G}_1^m$ is the 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 $\mathbb{G}_2^m$ is that for region 2. $\mathbb{G}_2^m$ is expanded in the series of normal modes of the rectangular waveguide (a x b) in Fig.3. For the reduction of eq.(1) to a system of linear equations, Galerkin's method of moments is adopted. To this end, $\mathbf{E}_i$ is approximated by a quasi-static field with only one unknown coefficient. Once the coefficient for each slot is determined, the inner field perturbed by slot coupling is derived easily in the form:

$$A(z)=A_0 \exp\{(-\alpha-j\zeta k_0)z\} \tag{2}$$

where α and ζ are the coupling factor and the slow wave factor [4]. These are compared with the measured ones.

3.Numerical Results and Discussion

Frequency characteristics of α and ζ are calculated for various design parameters and compared with the measurements. The antenna parameters used in the calculation are listed Table 1. Figures 4, 5 and 6 shows the results for the different slot length, the different permitivity of the dielectric and the height of the waveguide, respectively. As a whole, the calculated values and the measured ones are in good agreements. The increase in the coupling factor and the rapid change in the slow wave factor around the resonant frequency is predicted satisfactorily. The effects of the change of the antenna parameters is well described. The resonant frequencies as well as the serious perturbation due to the slot coupling are accurately predicted. The discrepancies near resonance are acceptable since smaller coupling of about $\alpha \simeq 5$ at non-resonant frequency are used practically.

4.Conclusion

The slot coupling in a RLSA is analyzed. We propose a simple model to simulate the slot excitation in the peripheral region of a RLSA. The boundary value problem is solved numerically using the normal mode function for the periodic structure. The calculated values are verified by experiments. It accurately expresses the effects of the design parameters upon the slot coupling. This analysis provides the basic method for the advanced design of a RLSA.

Reference

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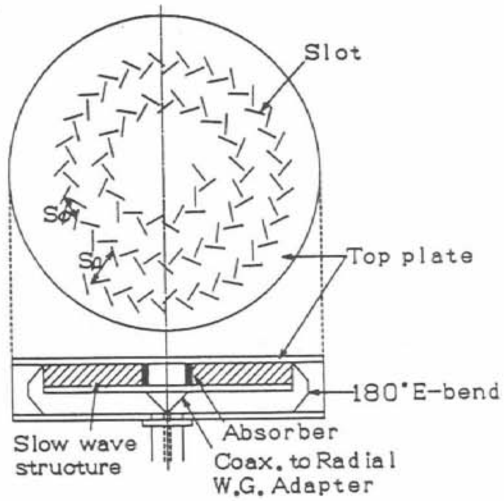

Fig.1 Construction of RLSA

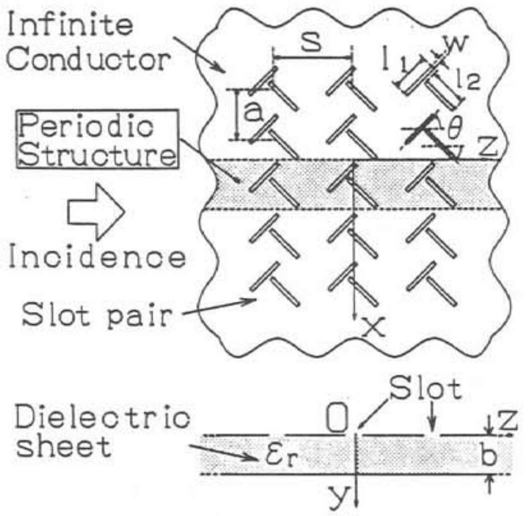

Fig.2 Analysis Model

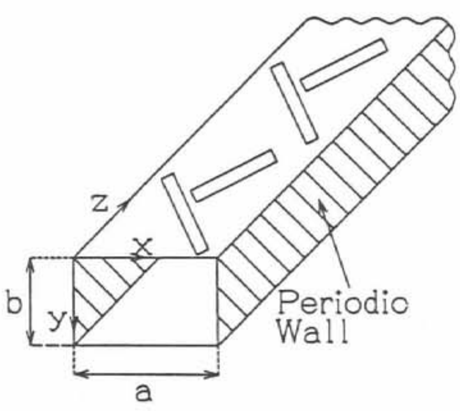

Fig.3 Periodic Structure

Slot Length	l_1	9.375 mm
	l_2	9.375 mm
Slot Width	w	1.0 mm
Coupling Angle	θ	45 deg
Slot Pair Spacing in z direction	s	20.0 mm
Slot Pair Spacing in x direction	a	10.0 mm
Waveguide Thickness	b	7.5 mm
Permitivity of Dielectric Sheet	ε_r	1.48
Number of Slot pair in z direction		9

Table 1 Antenna Parameters

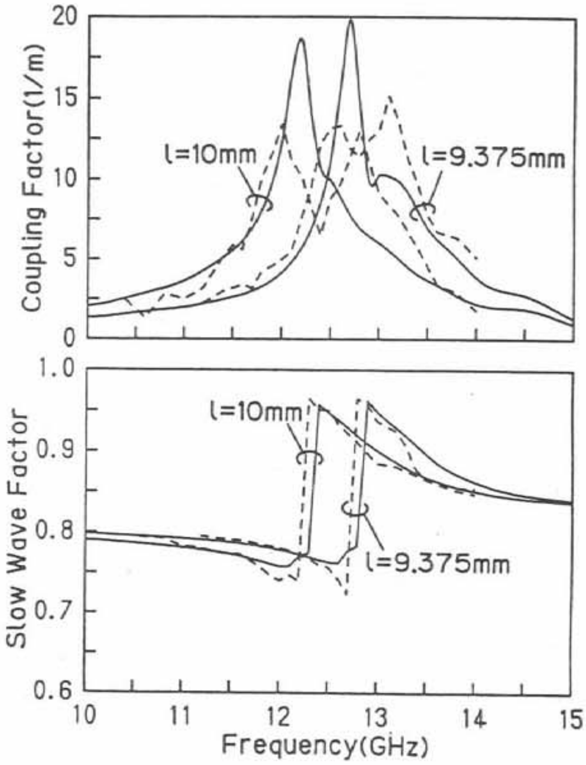

Fig.4 Frequency Characteristics of Coupling Factor and Slow Wave Factor of Different Slot Length

[Solid Line : Calculated
Dotted Line : Measured]

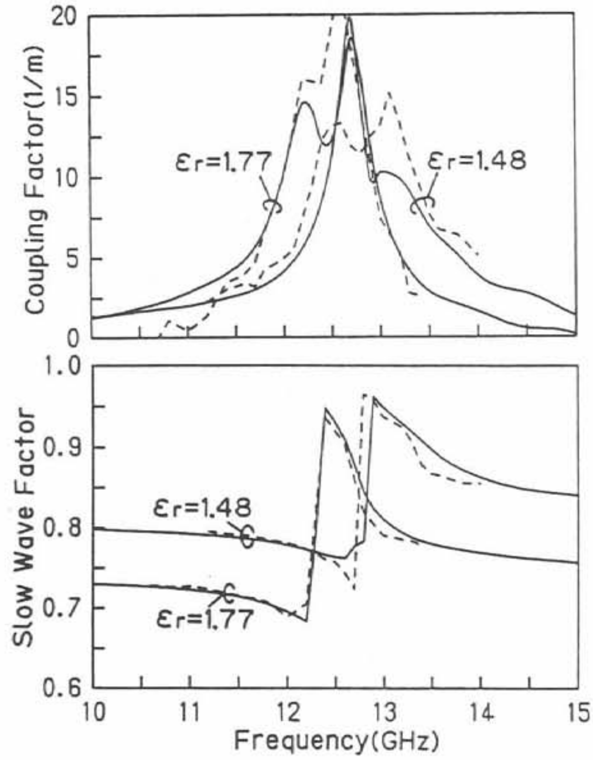

Fig.5 Frequency Characteristics
of Coupling Factor
and Slow Wave Factor
of Different Permitivity
of Dielectric
(Solid Line : Calculated
Dotted Line : Measured)

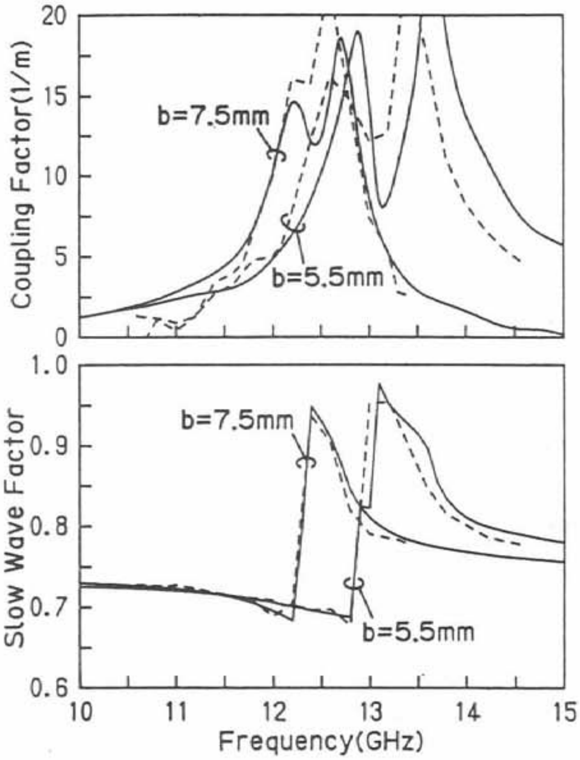

Fig.6 Frequency Characteristics
of Coupling Factor
and Slow Wave Factor
of Different Height
of Waveguide
(Solid Line : Calculated
Dotted Line : Measured)