ANALYSIS AND DESIGN OF FEEDING STRUCTURES FOR MICROSTRIP LEAKY WAVE ANTENNA

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ABSTRACT

Two methods to excite the microstrip leaky wave antenna are proposed and investigated in this paper. A full-wave spectral domain integral equation method combined with fundamental mode sampling technique is applied to determine the reflection coefficient of the excitation source. Dependence on structural parameters such as line width, overlap length and line spacing is fully analyzed to obtain the optimum excitation for microstrip leaky wave antenna. Also, an experimental setup is performed to check the validity of our numerical results and identify the radiation nature of the microstrip line higher order modes.

INTRODUCTION

Although microstrip line is not a low loss guide, yet with its features of low profile, structural simplicity, easier fabrication and suitability for integrated design, the leaky wave antenna based on it is worthy of further consideration for applications in integrated antenna. Microstrip leaky wave antenna with first higher order mode excitation radiates power in the narrow frequency regime before cutoff. The radiation main-bean depends on the operating frequency. Therefore it can be used as a frequency-scanning antenna [1].

The propagation properties of microstrip line higher order modes were first studied by Ermert [2]-[3]. He used an accurate mode-matching method to find the propagation charateristics of the dominant mode and first two higher order modes, but he failed to obtain real solutions near the cutoff of the higher order modes. He therefore called the range as "radiation" range, but did not further explain. Oliner and Lee clarified the confusion of properties of microstrip line higher order mode and showed that the radiation occurs in two forms, surface wave and space wave [4]. In [5] Oliner pointed out that if the microstrip line has a top cover, the power radiated into space wave will increase with increasing height of the top cover. When the top cover is removed, most of the power radiates into space wave. The fact indicated the efficiency of the microstrip leaky wave antenna. Recently, Nyquist proposed a rationale for the specification of the radiation spectrum associated with open microstrip line and made the choice of the branch cut in the spectral domain analysis clearly in physics [6].

There is much effort made to characterize the propagation properties of microstrip line higher order modes, but little about the excitation of these modes. The principles of design of feeding structures for leaky wave antenna are the suppression of dominant mode and the excitation of only first higher order mode. Menzel had proposed a sucessful method for the excitation of the microstrip line first higher order mode [7]. He used an asymmetric feed arrangement with a sequence of transverse slits on the center of the microstrip line to suppress the microstrip line dominant mode. In this paper, we propose two arrangements of feeding structures, one is slotline-fed structure and the other is coplanar strips(CPS)-fed structure. These types of excitation can fully suppress the dominant mode and obtain higher efficiency. In this paper, for full consideration of the physical phenomena, we employ a full-wave spectral domain integral equation technique and the method of moments to find the reflection coefficient of the excitation source. The method can properly include surface wave and space wave effects. Additionally, the fundamental mode sampling technique [8] is used to simulate the excitation mode and the leaky mode. This makes the types of bases used in the moment method fewer and simple. By employing this method, various dimentional parameters of structure are analyzed to obtain the optimum design of the feeding structure.

RADIATION CHARACTERISTICS OF MICROSTRIP LINE HIGHER ORDER MODES

The microstrip line higher order modes can radiate power into surface wave and space wave only in a narrow frequency range before cutoff. we can divide the propagation modes into the following four regions:

a. $\beta > \beta_s, \alpha = 0$, bound mode region.

b. $\beta_s > \beta > k_0, small\ \alpha$, surface wave leakage region.

c. $k_0 > \beta, small\ \alpha$, surfave wave and space wave leakage region.

d. $k_0 > \beta, large\ \alpha$, cutoff region.

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where β is the propagation constant of microstrip line higher order mode, β_s is the propagation constant of surface wave mode of surrounding structure and k_0 is the wavenumber in the air. In frequency region d, large α of the complex propagation constant does not mean that the radiation is strong for the microstrip line higher order mode. Instead, the higher order mode is in the cutoff region[5]. So microstrip line can be used as a leaky wave antenna only in region c.

PROPOSED FEEDING STRUCTURES

The feeding structures proposed in this paper are shown in Fig. 1. The structure in Fig. 1(a) consists of microstrip line and slotline. The slotline mode can be excited by microstrip line dominant mode in the orthoganal direction [8]. The structure in Fig. 1(b) consists of microstrip line and CPS. The CPS mode can be excited by microstrip line 180° hybrid or coplanar waveguide (CPW) to CPS transition [9]. These two types of feeding structures can fully suppress the microstrip line dominant mode by the symmetric properties of field distribution. For the impedance matching, we can use tapered feeding lines to obtain optimum matching.

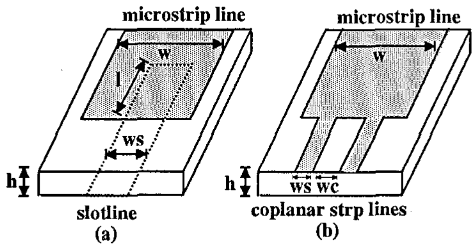

Fig. 1 Two feeding structures for the excitation of microstrip line higher order mode.

FULL-WAVE SPECTRAL DOMAIN ANALYSIS

In traditonal moment method, an exponential term is used to represent the propagation mode [10], resulting in complexity in modeling and more computational effort needed. In this paper, we use an expansion in terms of local basis functions (piecewise sinusoidal functions or triangle functions) to represent the exponential term. This method is called the fundametal mode sampling technique in [8]. For example, we can represent the $e^{j\beta x}$ by the following equation:

$$e^{j\beta x} = \sum_{n=1}^{n_{max}} I_n B(H - |x - x_n|)$$

$$I_n = e^{j\beta x_n}$$

where I_n is the amplitude of basis functions, B represents the basis used for simulation, H is half width of the local basis function, x_n is the location of the basis function and n_{max} is the number needed to represent the propagation mode for numerical convergence. The Green's functions, matrix blocks and integrals involved in this analysis are well known [8], [10], and are not reiterated here.

NUMERICAL RESULTS AND MEASUREMENT

The efficiency of excitation for microstip line first higher order mode fed by slotline and CPS with various dimensional parameters has been investigated in this paper. The numerical results are compared with those in [7]. The operational frequency is 7 GHz, chosen in the center of the radiation region. The numerical results and experimental data are summarized as following statement.

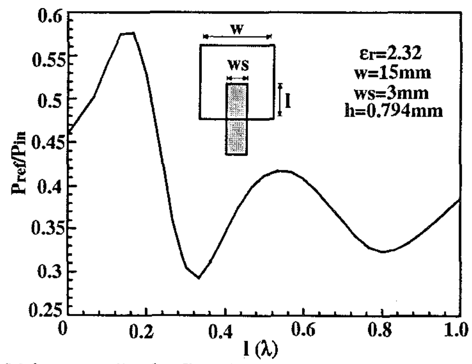

Fig. 2 The normalized refleced power as a function of overlay length in the unit of slotline wavelength.

A. Slotline-fed Structure

After analyzing and comparing our numerical results, we find that the efficiency in the case of slotline-fed structure depends mainly on the width of slotline and the overlap length between microstrip line and slotline. The typical pattern of efficiency, exhibiting the periodic change due to various overlap lengths, is shown in Fig. 2. The period is almost half guided wavelength of slotline. The influence of the slotline width is shown in Fig. 3 with the optimum overlap length. They show that wider slotline has better efficiency. When the width is beyond 8 mm, the efficiency is better than that in [7]. Additionally, we find that the optimum overlap length with different slot width change from 0.4λ to 0.3λ of slotline mode by changing the slot width from 1mm to 13mm. In our analysis, the wavelength of microstrip line first higher order mode is between 1.5 to 1.7 slotline guided wavelength. So the optimum overlap length is between $\lambda/4$ of slotline mode and $\lambda/4$ of microstrip line first higher order mode. They show that wider slotline needs shorter optimum overlap length.

B. CPS-fed Structure

The efficiency of excitation for microstrip line first high or-

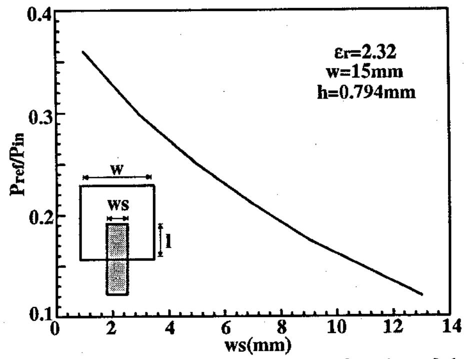

Fig. 3 The normalized reflected power as a function of slotline width when the optimum overlap lengths are used.

der mode in case of CPS-fed structure also depends mainly on the stuctural parameters, the strip width of CPS and the strip spacing of CPS. The efficiency due to different strip widths of CPS is shown in Fig. 4. We find that the efficiency is higher when the strip width is narrower. And the efficiencies are better than those in [7] for all cases in Fig. 4. The effect caused by different spacings of strips is also shown in Fig. 5 with strip width equal to 3.75mm. Also, it has the same effect as that shown in Fig. 5 when the strip spacing is changed. Additionally, it is shown that the optimum positions of the strips of CPS are almost at the middle points between the center and the edges of microstrip line. After full analyzing and comparing, we find if we use the narrower strip width and place the strip near the optimum position, there is almost no power reflected back. Namely, the efficiency is very high.

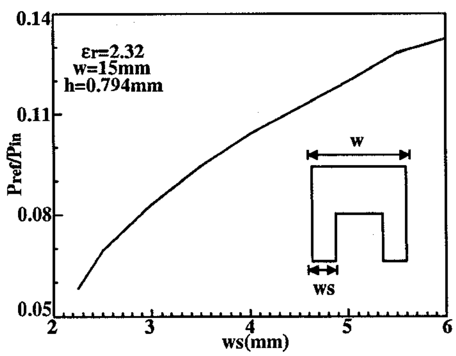

Fig. 4 The normalized reflected power as a function of the width of coplanar strip lines.

Finally, we compare the results of the CPS-fed structures with those of slotline-fed structures. We find that the efficiency is better for CPS-fed structures. Although CPS-fed structure is better in efficiency than the slotline-fed structure, it needs either a microstrip line 180° hybrid or a CPS to CPW transition to generate the CPS excitation mode. This transition circuit must be properly designed to obtain better efficiency in the overall circuit.

C. Measurement

In this paper, an experimental setup shown in Fig. 6 is performed to check the validity of the analysis results obtained. The efficiency for various overlap lengths is shown in Fig. 7. The measured results are shown in Fig. 8 to validate our numerical results. They show that the power dissipation is large with the $\lambda/2$ overlap length, and therefore agree well with our numerical results in Fig. 7. In Fig. 8, the cutoff region is in the lower frequency region, where there is almost no power dissipation. In the middle frequency region, the larger power dissipation is due to the radiation. The ripple in higher frequency region is due to the resonance of bound microstrip line first higher order mode. A 3 dB power dissipation due to the conductor loss is also observed.

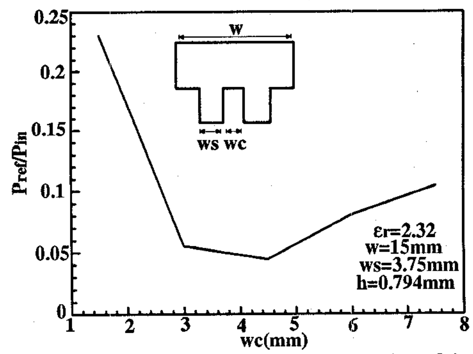

Fig. 5 The normalized reflected power as a fuction of the spacing of coplanar strips.

CONCLUSIONS

The propagtion properties of microstrip line first higher order mode have been clarified by our measurement. Also, the design rule of the feeding structure is proposed after our analysis. In slotline-fed structure, the optimum excitation is obtained with wider width of slotline and overlap length between $\lambda/4$ of slotline and microstrip line first higher order mode in low dielectric constant structure widely used in antenna applications. But the use of wider slotline must satisfy the condition that no extra higher order mode with the same symmetric property of slotline dominant mode is excited. In CPS-fed structure, the optimum excitation is obtained with narrower strip width and with the strip positions at the middle points between the center and the edges of microstrip line. Although CPS-fed structure is better in efficiency than the slotline-fed structure, it needs either a microstrip line 180° hybrid or a CPS to CPW transition to generate the CPS excitation mode. This transition circuit must be properly designed to obtain better efficiency in the overall circuit.

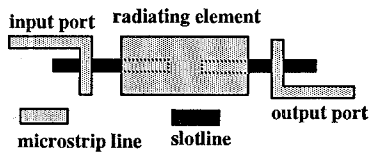

Fig. 6 The experimental setup used to excite the microstrip line higher order mode.

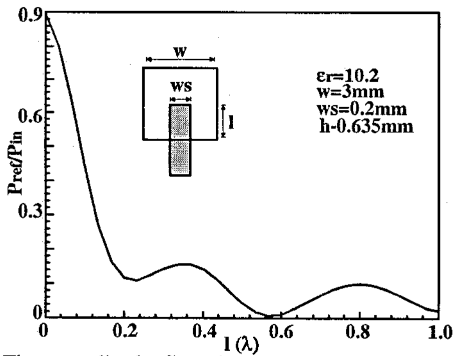

Fig. 7 The normalized reflected power as a function of overlap length in the unit of slotline wavelength with high dielectric constant structure.

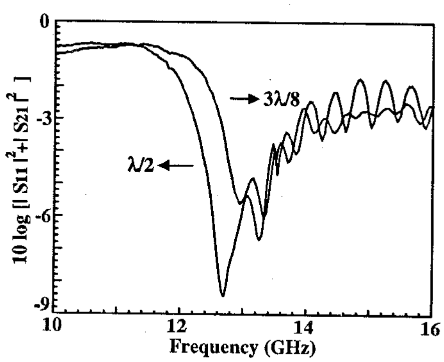

Fig. 8 The power dissipation with different overlap lengths in our experiment.

ACKNOWLEDGMENT

This work was supported in part by National Science Council under the grants: NSC 84-2623-D-009-009 and NSC 84-2221-E-009-012.

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