Mode-Coupling Phenomena of the Even Modes on Microstrip Line

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Abstract

Mode-coupling phenomena of the even modes on microstrip line are presented in this paper. These phenomena occur when the dispersion curve of the microstrip line leaky dominant mode is close to those of the conventional microstrip line dominant mode or the microstrip line higher order modes. Interesting mode-coupling and mode evolution patterns are observed. Current distributions of the modes near the mode-coupling region are also shown. The ways to control the coupling region by the geometric parameters and to avoid the excitation of the microstrip leaky dominant mode in designing a leaky-wave antenna are discussed based on these mode patterns.

Introduction

Possible surface-wave leakage of dominant modes [1]-[5] and space-wave leakage of higher order modes [6]-[9] on different planar transmission line are intensively investigated in recent years. There are always complicated mode-coupling phenomena or mode evolution phenomena happening near the onset of surface wave leakage. In [2]-[3], two nonspectral real modes evolve into a leaky mode due to the mode-coupling effect between the surface-wave-like mode and the conventional dominant mode. In [4]-[5], the modes evolve in different ways due to different geometric parameters. There are many literatures published for these phenomena, especially for the dominant mode. However, few results concerning these phenomena involving the higher order modes are found in the literature.

Investigations of space-wave leakage of planar transmission line are motivated by developing a low-cost millimeter wave antenna [10]-[11]. The researches mainly focused on the microstrip line first higher order mode (the odd mode). In recent years, new applications [12] show that dual-beam antennas might be useful. This leads to the investigation of the microstrip second higher order mode (the even mode) as a possible line source [13]. These higher order modes are used as an antenna in the radiation region in [9]. The radiation region is defined as the fast wave region where the phase constants of the modes are smaller than the free space wave number. It is found that there is no mode-coupling happening in the odd modes of the microstrip line. Yet, in the even modes of the microstrip line, mode-coupling phenomena between the leaky dominant mode named in [3] and the even modes of the microstrip line are found. In [3], mode-coupling phenomena between the microstrip line dominant mode and the leaky dominant mode was proposed. In this paper, we will present mode-coupling phenomena between the leaky dominant mode and the even higher order modes. Understanding of this phenomena is essential in designing a leaky-wave antenna based on the microstrip even higher order modes, since the simultaneous excitation of the leaky dominant mode will reduce the antenna efficiency and cause cross talk to the neighboring circuits. After our investigation, we find that the current distribution of the leaky dominant mode is no longer similar to that of the conventional dominant mode. It is similar to that of the higher order mode near the mode-coupling region. So when we use the microstrip line second higher order mode as a leaky wave line source, the leaky dominant mode is hard to be suppressed by the method employed in [13]. Fortunately, this simultaneous excitation of the microstrip line leaky dominant can be avoided by thinning the substrate thickness. The thinning will move the microstrip line leaky dominant mode to higher frequency range, but has little effect on the radiation region of the microstrip line second higher order mode.

Mode Evolution Patterns of the Even Modal Group on Microstrip Line

Shown in the inset of Fig. 1 is the structure of microstrip line with a magnetic wall placed at the center. The constituent modes on such structure are with magnetic wall symmetric property. Since the symmetric property forces the longitudinal currents on the microstrip line to be of even symmetry, we call the constituent modes of such structure as the even modes of the microstrip line. Mode-coupling phenomena of the leaky dominant mode and the even modes on microstrip line are first proposed in [3]. In [3], it is found that two nonspectral real surface-wave-like modes evolve into the leaky dominant mode in the mode-coupling region as shown in Fig. 1.

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In the mode-coupling region the field distributions of the conventional microstrip line dominant mode and the leaky dominant mode are very similar, so the leaky dominant mode can be easily excited when we launch power into the microstrip line circuit, or when circuit discontinuities are present. Because the line width of the structure analyzed in [3] is not wide enough, no mode-coupling phenomena involving the higher order modes are observed. In open planar transmission lines, the frequency range of the occurrence of surface-wave leakage or mode-coupling phenomena is mainly determined by the substrate thickness and the dielectric constant of the substrate, but not by the line width. However, the radiation range of the higher order modes in open planar transmission lines can be controlled by scaling the line width. Therefore, if substrate parameters are fixed, the frequency range that mode-coupling between the leaky dominant mode and the conventional microstrip line dominant mode occurs is fixed. By varying the line width of the microstrip line, we can move the radiation region of the higher order modes and observe different mode-coupling phenomena. Using the same substrate parameters as those in Fig.1 and a wider line width, we can obtain the dispersions curves of even modes depicted in Fig. 2. To discuss the mode-coupling phenomena between these modes in Fig. 2, we divide the frequency region into the lower frequency region and the higher frequency region. In lower frequency region of Fig. 2, the radiation region of the higher order mode (the second higher order mode) is in the frequency region where the leaky dominant mode is not formed yet. It is found that the dispersion curves of the nonspectral real modes in Fig. 1 do not combine together. Instead, the lower dispersion curve of the nonspectral real mode connects with the dispersion curve of the bound second higher order mode. Further, a nonphysical second higher order mode evolves into two nonspectral real mode after the connection point mentioned above. The nonphysical complex second higher order mode is obtained by choosing proper Remann sheet and is not shown in Fig.2. Then these two modes evolve into the leaky dominant mode as shown in Fig. 1. In the higher frequency region of Fig. 2, the radiation region of the higher order mode (the fourth higher order mode) is in the frequency region where the leaky dominant mode already exists. In this case, mode-coupling between physical modes may occur. It is found that in the mode-coupling region the dispersion curve of the leaky dominant mode will rise above the dispersion curve of the TM_0 mode, then evolves into two nonspectral real mode. The lower nonspectral real mode finally evolves into the real microstrip fourth higher order mode. Additionally the fourth higher order mode will evolve into the leaky dominant mode. This interesting mode-coupling phenomenon is worthy of careful inspection in designing a leaky-wave antenna.

To design an efficient feeding structure for the leaky-wave antenna based on higher order modes, it is best that only the desired higher order mode is excited. In [11], this can be successfully achieved for the first higher order mode of microstrip line. However, this one-mode excitation is not possible in the applications of the even microstrip line higher order modes, since the conventional microstrip line dominant mode and the leaky dominant mode can not be fully suppressed. If the leaky dominant mode is always similar to the conventional microstrip line dominant mode as described in [3], the method using the difference of current distribution in [14] can be employed to enhance the simultaneous suppression of the microstrip line dominant mode and the leaky dominant mode. Unfortunately, in the mode-coupling region of the leaky dominant mode and the microstrip line even higher order mode, the modes are very similar to each other. Therefore, the leaky dominant mode can not be sufficiently suppressed by the method mentioned above. Shown in Fig. 3 are the current distributions of the two nonspectral real mode and the second higher order mode in the mode-coupling region. They are very similar to each other. Additionally, shown in Fig. 4 are the current distributions of the leaky dominant mode and the fourth higher order mode in the mode-coupling region. They are also similar to each other. Therefore, to use the even higher order mode as a leaky wave line source, the radiation region should be chosen in which the leaky dominant mode is not formed yet. And mode-coupling between the leaky dominant mode and the desired even higher order mode should be avoided. These can be achieved if the substrate parameters are judiciously chosen. For instance, using thinner substrate can move the occurrence of the leaky dominant mode way higher in the frequency region.

Conclusions

Mode-coupling phenomena between the leaky dominant mode and the microstrip line even higher order modes are discussed in this paper. Current distributions of the modes in the mode-coupling region show the difficulty of suppressing the undesired leaky dominant mode in leaky-wave antenna application. The only way to avoid this problem is placing the radiation region of the higher order mode in the frequency region where the leaky dominant mode is not formed yet. Using a thinner substrate can achieve this.

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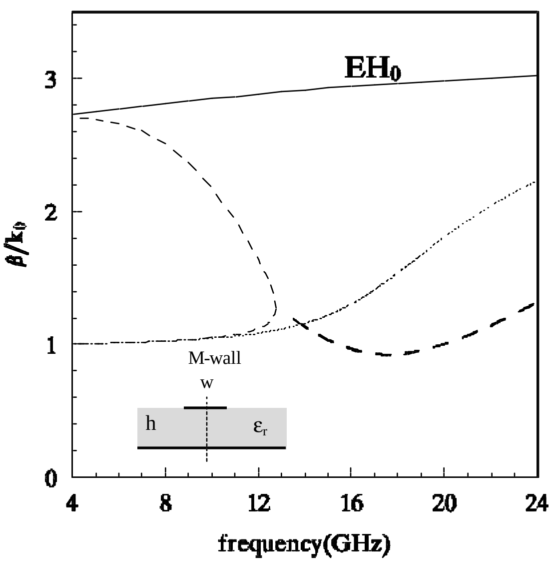


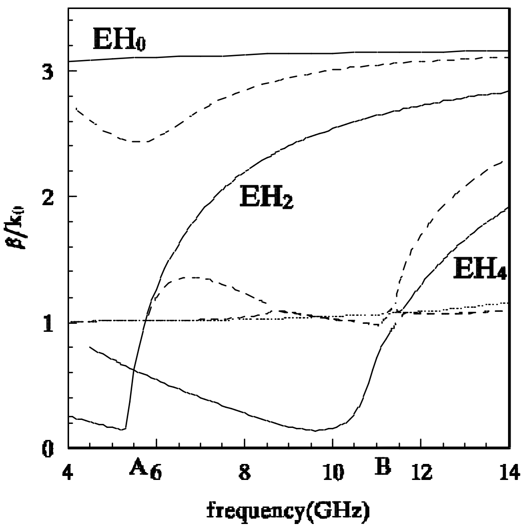
Fig. 1. Dispersion curves of the even modes on the microstrip line shown in the inset. w=2mm, h=1.27mm, ε_r=10.2.

— dominant mode

… TM_0

--- improper mode(nonspectral real)

-- leaky dominant mode



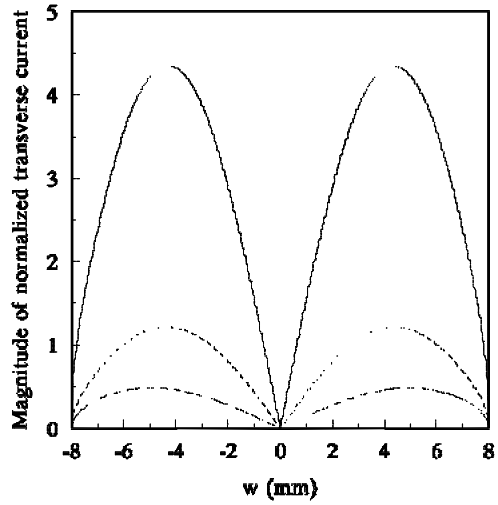
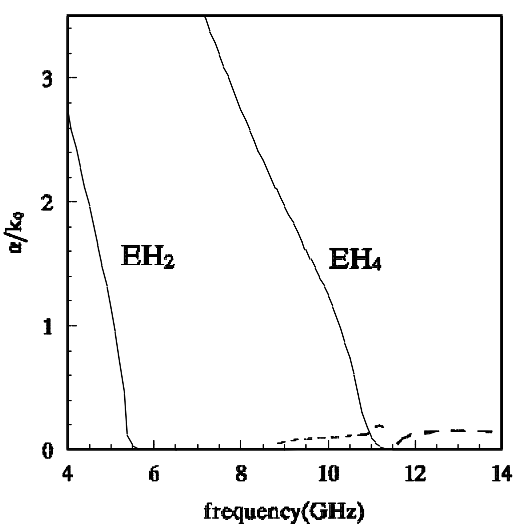


Fig. 2.(a) Normalized phase constants of the even modes on the microstrip line shown in the inset of Fig.1. w=16mm, h=1.27mm, ε_r=10.2.
— dominant mode and even higher order modes
… TM_0
--- improper mode (nonspectral real)
-- leaky dominant mode

Fig. 3. Magnitude of transverse current distributions normalized to the longitudinal center current for f=5.6 GHz(A) in Fig.2(a).
… improper mode (the lowest line, nonspectral real) near the dominant mode
--- improper mode (nonspectral real) near the 2nd higher order mode
— the 2nd higher order mode (leaky)



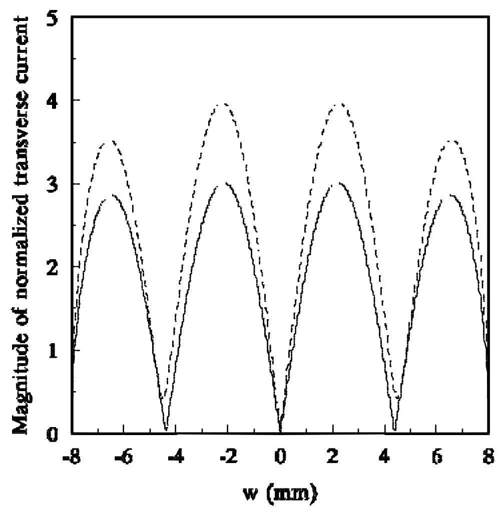


Fig. 2.(b) Normalized attenuation constants of the even modes on the microstrip line shown in the inset of Fig.1. w=16mm, h=1.27, ε_r=10.2.
— even higher order modes
-- leaky dominant mode

Fig. 4. Magnitude of transverse current distributions normalized to the longitudinal center current for f=11.2 GHz(B) in Fig.2(a).
--- leaky dominant mode near the 4th higher order mode
— the 4th higher order mode (leaky)