FDTD INVESTIGATION OF HIGHER ORDER MODE LEAKAGE FROM THREE DIMENSIONAL MICROSTRIP LINE STRUCTURES

Zhewang Ma and Eikichi Yamashita
University of Electro-Communications
1-5-1 Chofugaoka, Chofu-shi, Tokyo 182, Japan

ABSTRACT

Electromagnetic field leakage phenomena associated with the first higher order mode of an asymmetrically fed microstrip line structure is investigated by using the FDTD method. From the obtained scattering parameters and loss factor of the three-dimensional microstrip line structure, leakage properties of the first higher order mode at different frequencies are made clear, and they confirm the predictions of the two-dimensional transmission line analysis. Experimental measurements are implemented and the measured data are in favorable agreement with the simulated results.

INTRODUCTION

Radiation of fields from the higher order modes on microstrip lines was studied first by Ermert [1], and was experimentally observed later by Menzel [2]. In [3] and [4], Oliner and Lee investigated and explained the nature of leakage from the higher order modes on microstrip lines, and clarified the confusion remained in [1] and [2] regarding the properties of microstrip line higher order modes. Up to date, there have been quite a number of publications on the propagation properties of higher order modes on microstrip lines [5]-[10].

The continued interest in the study of leakage characteristics of higher order modes on microstrip lines is attributed to the fact that, this type of leakage of power may produce unwanted cross talk between neighboring parts of a circuit and unexpected package resonance effects, or it can be used to create new circuit components and antennas. Most of the up to date publications pertaining to the higher order modes of microstrip lines addressed two-dimensional transmission line problems. They specified the radiation spectrum and radiation characteristics of higher order modes on microstrip lines that are homogeneous along the propagation direction. However, since most of the microwave circuits and leaky wave antennas are of three dimensional configurations, the accurate characterization of leakage from the higher order modes on microstrip lines in a three dimensional environment is necessary in the design of microwave circuits and antennas.

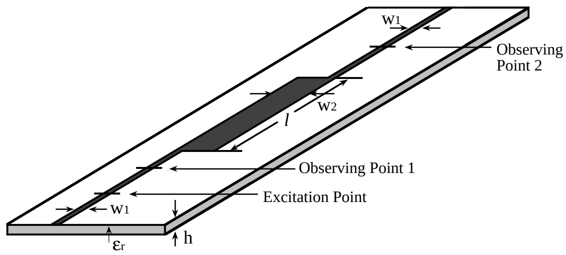

Figure 1: Asymmetrically fed microstrip line double step structure.

ANALYSIS AND RESULTS

In this paper, we investigate the leakage characteristics of the first higher order mode on an asymmetrically fed microstrip line by employing the FDTD method. The configuration of the studied structure is illustrated in Fig. 1, where a wider microstrip line of width w_2 and length l is fed by two input lines both with a width w_1. These two input lines are arranged in an asymmetrical fashion with respect to the wider microstrip line so that the first higher order mode of the wider microstrip line can be excited at appropriate frequencies [2][7].

Geometrical dimensions of the studied structure are h=1.52 mm, w_1=3 mm, w_2=15 mm, and l=40 mm. The dielectric constant of the substrate is ε_r=2.17. Before excuting FDTD analysis of this structure, we calculated the complex propagation constant of the first higher mode of the wider microstrip line with w_2=15 mm by using the mode-matching method [8], [12]. The results are plotted in Fig. 2. In this calculation, lateral metal walls of semi-infinite length, as shown by the inset of Fig. 2, are used to shield the microstrip line in the transverse direction so that the mode-matching analysis can be easily implemented [8], [12]. Compared with the completely open microstrip line, the values of the com-

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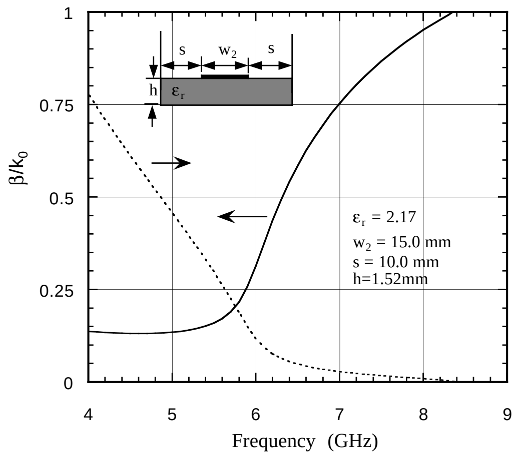

Figure 2: Frequency dependence of the normalized phase constant and leakage constant of the first higher order mode on a microstrip line.

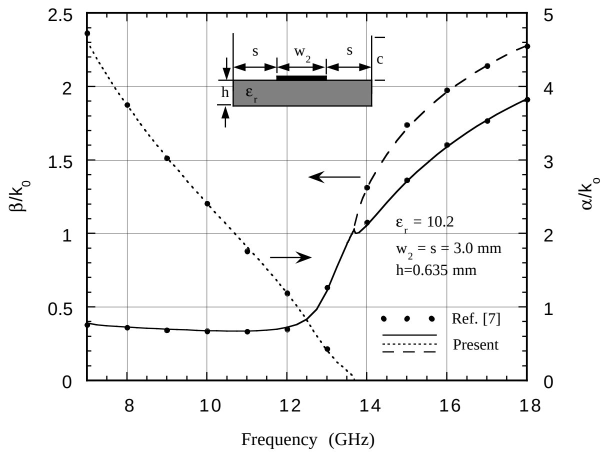

Figure 3: Comparison between the values of the phase constant and leakage constant of the first higher order mode on a microstrip line calculated by different methods.

plex propagation constant here varied by some degree at the low frequencies because of the influence of the shielding walls. The different propagation behaviors of the first higher order mode at different frequencies can be classified from this figure. We see that at frequencies greater than about 8.4 GHz, the normalized phase constant β/k_0 is larger than unity, and this frequency region is the bound wave (real spectral) region. As the frequency decreases down from 8.4 GHz, the value of β/k_0 becomes less than unity. Then, the mode moves from the bound wave region into the leaky wave region. The value of the leakage constant α/k_0 increases quickly with the decrease of frequency. When the value of α/k_0 becomes large, the mode is reactive and below cutoff. In the cutoff frequency region, little leakage of power will occur [4].

Another example we examine in this paper has structural parameters h=0.635 mm, w_1=0.63 mm, w_2=3 mm, l=40 mm, and ε_r=10.2. In Fig. 3 the frequency-dependence of the complex propagation constant of the first higher order mode of the wider microstrip line with a width w_2=3 mm is shown. Compared with Fig. 2, the phase constant and leakage constant here show quite steeper variation rates with frequency in the leaky wave region. The threshold frequency between the bound wave region and the leaky wave region of this microstrip line is about 13.7 GHz. A small transition region between the bound wave region and the leaky wave region [13] can also be seen in Fig. 3. The dashed line represents a real nonspectral solution [13]. In Fig. 3, the calculated results of [7] by the space-domain integral equation method are also drawn for comparison. Good agreement is found between the results obtained by this paper and by [7].

Next the leakage characteristics of the asymmetrically fed microstrip line structure shown in Fig. 1 are investigated. We calculate and examine the scattering parameters of this three dimensional structure by using the FDTD method. In the FDTD simulation, Mur's second order absorbing boundary condition is used to enclose the structure, including the two feeding microstrip lines, to form a finite computation domain. This computation domain is then divided into many small Yee's orthogonal cells. The feeding line is launched at the excitation point, shown in Fig. 1, by using a Gaussian pulse with desired spectrum width. Temporal field components at all of the cells in the computation domain are iterated in sequence for 5000 times. At the observing points 1 and 2 shown in Fig. 1, the calculated temporal field components are recorded as the reflected and transmitted pulses. After performing the Fourier transform of the obtained incident, reflected and transmitted pulses, we get the scattering parameters of this asymmetrical microstrip double step structure in the designated frequency range.

Structural parameters of the first example are given here again: h=1.52 mm, w_1=3 mm, w_2=15 mm, l=40 mm, and ε_r=2.17. The calculated scattering parameters, $|S_{11}|$ and $|S_{21}|$, are shown in Fig. 4. A loss factor, defined as $|S_{11}|^2+|S_{21}|^2$, can express more explicitly the loss of power occurred to the structure. The loss factor is also drawn in Fig. 4. We see that in the frequency range 5.5 $\sim$ 8.4 GHz, the value of the loss factor drops down rapidly, implying great loss of power. This confirms the result of Fig. 2, which indicated that when

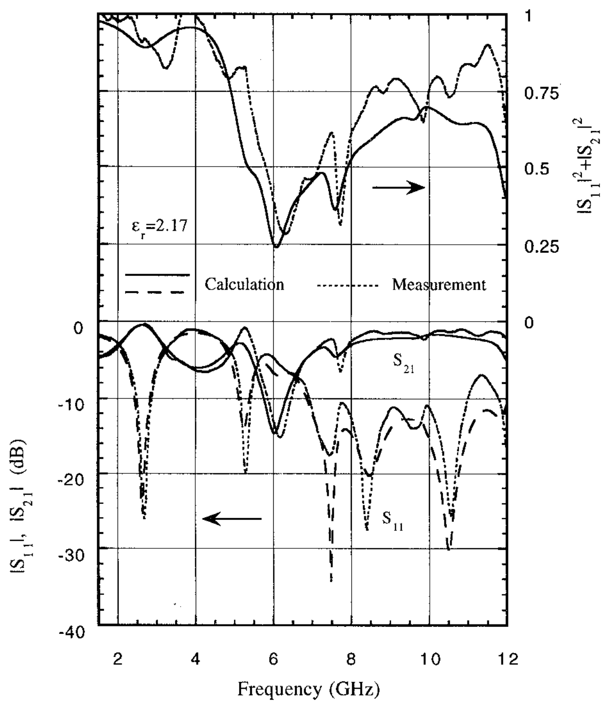

Figure 4: Comparison between the calculated and measured scattering response and loss factor of the asymmetric microstrip double step structure with ε_r=2.17.

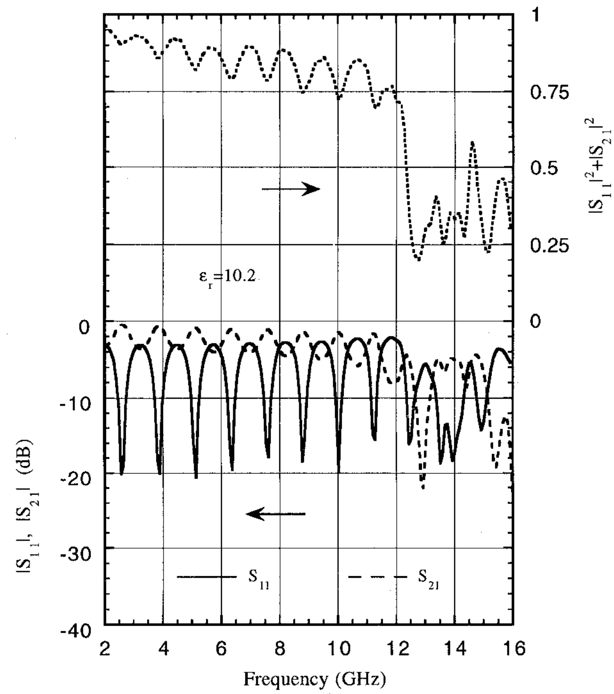

Figure 5: Calculated scattering parameters and loss factor of the asymmetric microstrip double step structure with ε_r=10.2.

the frequency is lower than the threshold frequency 8.4 GHz, the first higher order mode of the wider microstrip line is leaky. In Fig. 2 we see also that when f < 5.5 GHz, the value of the leakage constant of the first higher order mode is vary large. However, in Fig. 4, we found that the value of the loss factor in this frequency region is large, meaning very weak leakage of power. This justifies the theory of [4] that in the cutoff frequency region, little leakage of power will occur although the value of the leakage constant is quite large. We note that the two-dimensional analysis result of the complex propagation constant, shown in Fig. 2, tells exactly when the first higher order mode will become a leaky mode by giving the threshold frequency. However, it does not provide a clear indication of when the mode will enter the cutoff region and at which frequencies the mode will produce leakage of power most efficiently. The answers to these questions can be read explicitly from the result of the three-dimensional structure, particularly the loss factor in Fig. 4.

We measured the scattering response of the asymmetric microstrip double step structure by using an HP8510B network analyzer. The calibration of the measurement is implemented by applying the TRL method. The measured data are drawn in Fig. 4 by dotted lines, and are compared with the calculated results drawn in solid and dashed lines. It is seen that the calculated and measured scattering parameters agree fairly well, and the loss factors agree reasonably too. The discrepancy between the calculated and measured values may be attributed to the influence of the absorbing boundaries used in the FDTD simulation, and the calibration errors of the measurement. Other reasons may include, for example, the neglect of the dielectric and conductor losses in the FDTD calculation.

Structural parameters of the second example are: h=0.635 mm, w_1=0.63 mm, w_2=3 mm, l=40 mm, and ε_r=10.2. The calculated and measured scattering parameters and loss factors of this example are illustrated in Fig. 5 and 6, respectively. Again we found favorable agreement between the calculated and measured results. In the frequency range 12.0 $\sim$ 13.7 GHz, the value of the loss factor is very small, indicating strong leakage of power in this frequency region from the structure. This is explained in the same way as that of the first example above, using the complex propagation constant provided in Fig. 3. Compared with the variation of the loss factor of the first example shown in Fig. 4, the loss factor here demonstrates a much faster decrease in value in the leaky frequency region 12.0 $\sim$ 13.7 GHz. This agrees with the fact that the phase constant and

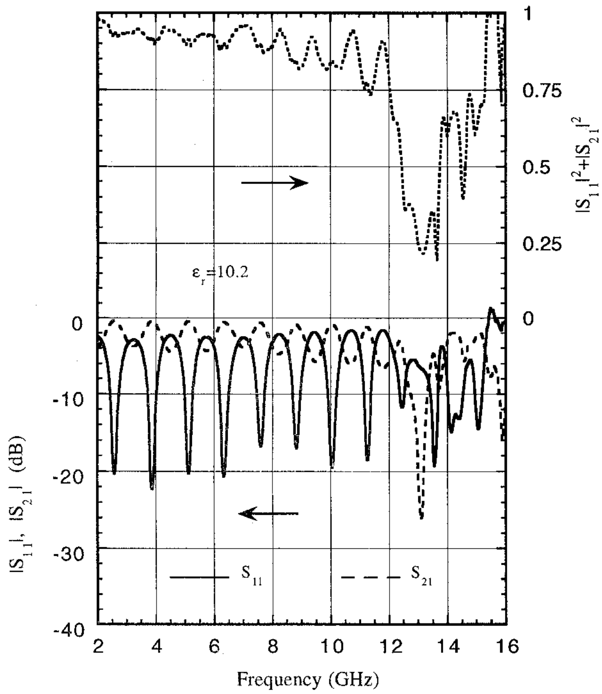

Figure 6: Measured scattering parameters and loss factor of the asymmetric microstrip double step structure with ε_r=10.2.

leakage constant of the second example own steeper variation rates with frequency in its leaky frequency region than those of the first example, as can be seen from Figs. 2 and 3.

CONCLUSION

To conclude briefly, we say that leakage phenomena associated with the first higher order mode on asymmetrically fed microstrip lines was investigated by using the mode-matching method and the FDTD method. From the obtained scattering parameters and loss factors of the three dimensional structures, leakage properties of the first higher order mode at different frequencies were made clear, and they confirm the predictions of the two-dimensional transmission line analysis made in this paper. Experimental measurements were implemented and the measured data were in favorable agreement with the simulated results.

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