Significant Contribution of Nonphysical Leaky Mode to the Fields Excited by a Practical Source in Printed-circuit Transmission Lines

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Abstract **— We were the first to report for printed-circuit transmission lines that nonphysical improper real solutions have significant effect to physical total field excited by a practical source. We have recently studied such interesting and unexpected effect in more detail, and we have discovered here that nonphysical leaky solution also causes a significant effect to physical near field excited by a practical source, contrary to earlier belief.**

I. INTRODUCTION

It is by now well known that the dominant mode on printed-circuit transmission lines is purely bound at lower frequencies and leaky at higher frequencies. It is also understood now that both regimes are completely separated by the spectral gap[1]-[3], or overlap, depending on the relative dimensions of the guide cross section[4][5]. Although these characteristics are found out from the dispersion behavior based on the eigenvalue analysis, there exist phenomena that cannot be expected from the dispersion behavior. One of them is the contribution of improper real solution to the physical near field excited by a practical source[6]. This solution, of which field is increased transversely, has been neglected as a meaningless nonphysical one in excitation problems, but we have actually observed in the range of some distance from a source that this solution behaves like a bound mode[7]. In this paper, we have discovered another phenomenon that nonphysical leaky solution behaves like a physical leaky solution. This solution that we call the LM_2 leaky one, leaks in the form of two surface waves on the surrounding dielectric substrate when its phase constant lies below both the dispersion curves of the surface waves. However this solution of which phase constant lies between their dispersion curves becomes nonphysical. In this case, we have observed that the field along the guide axis slowly decays away from the source, contrary to earlier belief. So we have investigated this phenomenon from the viewpoints of both the evolution of eigenvalue solutions and the application of GPOF[8] to the FDTD data. As a result, we have suspected that the decay of field along the guide axis is due to the indirect effect of the nonphysical LM_2 leaky solution.

II. CALCULATION RESULTS

We consider the conductor-backed coplanar strips as an example of planar transmission lines, of which the normalized phase and leakage constants for the structural parameters $w/h = 0.25$ and $d/h = 0.25$ are shown in Fig. 1. The dielectric constant of the substrate is $\varepsilon_r = 2.25$. The spectral gap appears between the frequencies f_{cr1} and f_{cr2} as seen, and the bound-mode and leaky-mode regions are completely separated. In this figure, the LM_1 mode (green line) represents the leaky mode that leaks only into the TM_0 surface wave, and the LM_2 (red line) is the leaky

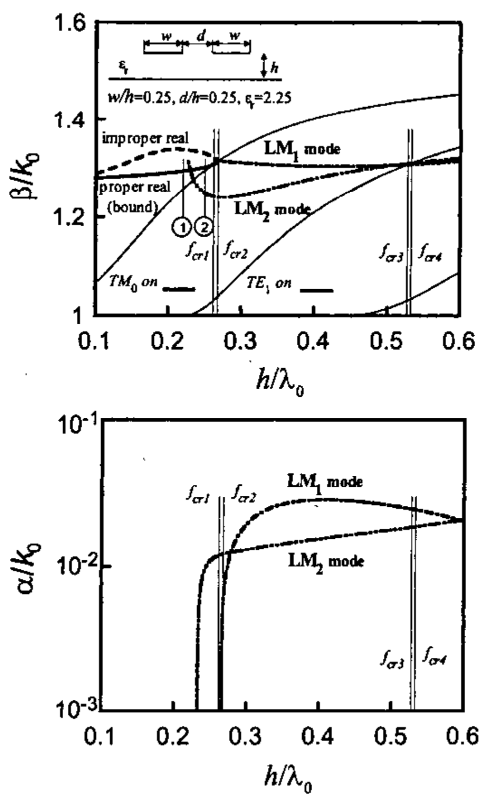

Fig. 1. Normalized phase and leakage constants for the conductor-backed coplanar strips for $w/h = 0.25$ and $d/h = 0.25$.

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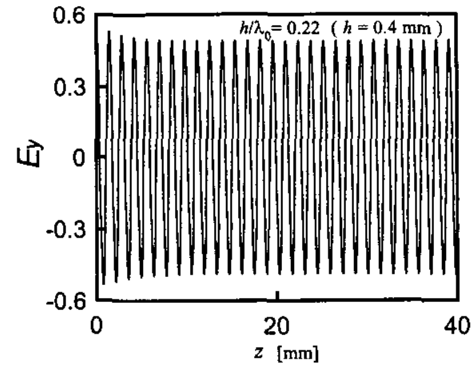
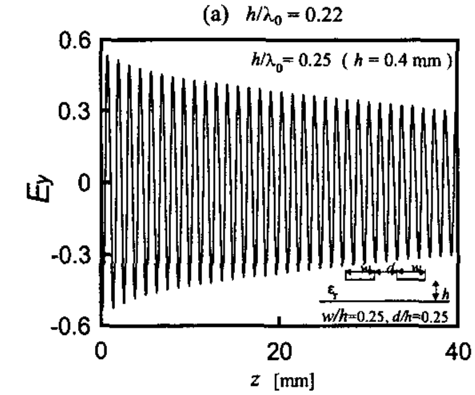
mode that leaks into both the TM_0 and the TE_1 surface waves. As the frequency is increased from the critical frequency f_{cr2}, the dispersion curve for LM_1 eventually crosses the dispersion curve for the TE_1 surface wave at the frequency f_{cr3}, and then above this frequency the LM_1 mode is nonphysical. While the LM_2 leaky mode is physical above the frequency f_{cr4} at which the dispersion curve for LM_2 crosses the dispersion one for the TE_1 surface wave, so that the LM_2 leaky mode is nonphysical below the frequency f_{cr4}. The transition between these two leaky solutions results in a new type of the spectral gap[9].

We first discuss the excitation problem for this guide by using the FDTD method. A monochromatic-frequency wave is excited, of which the field distribution on the guide cross section is given by the vector eigen function at the normalized frequency h/λ_0 = 0.02. We use the PML[10] as an absorbing boundary condition. Figure 2(a) shows the field-amplitude variation just on the substrate along the center of the guide, calculated at the normalized frequency $h/\lambda_0 = 0.22$. It should be noted here that the bound mode is the only physical solution at this frequency marked ① in Fig. 1. We find from this result that the field amplitude remains constant along the guide and we can conclude only the bound mode is excited.

Let us next change the normalized frequency from h/λ_0 = 0.22 to 0.25 marked ② in Fig. 1. Figure 2(b) shows the similar field-amplitude plots with that of Fig. 2(a). Although the physical solution in this frequency is again only the bound mode, we can see in this result that the actual field clearly decays along the guide, different from that in Fig. 2(a). We notice that a significant difference between Figs. 2(a) and (b) is observed in the evolution of the nonphysical LM_2 leaky mode. That is, as shown in Fig. 1, this LM_2 leaky solution does not exist at $h/\lambda_0 = 0.22$, while, at h/λ_0 = 0.25, this solution exists between the dispersion curves for the TM_0 surface wave and the TE_1 surface wave. This means that the LM_2 solution at h/λ_0 = 0.25 satisfies the physical condition for the leakage of the TM_0 surface wave, but does not satisfies for that of the TE_1 surface wave, so that this solution results in nonphysical solution. However, if the LM_2 modal fields outside the guide are predominantly constituted by the TM_0 surface-wave component, we expect this solution significantly contributes to the field near the excitation source. Figure 3 shows the field-intensity distribution on the xz plane just below the air-dielectric interface at the normalized frequency $h/\lambda_0 = 0.25$. It is obvious from this figure that the field decay shown in Fig. 2(b) is caused by the leakage into the surrounding dielectric substrate. The solid line depicted in the leakage field in Fig. 3 indicates the theoretical leakage angle of the TM_0 surface wave that is calculated from the phase constant of the nonphysical



(a) $h/\lambda_0 = 0.22$



(b) $h/\lambda_0 = 0.25$

Fig. 2. Plot of the field-intensity along the center of the guide shown in Fig. 1.

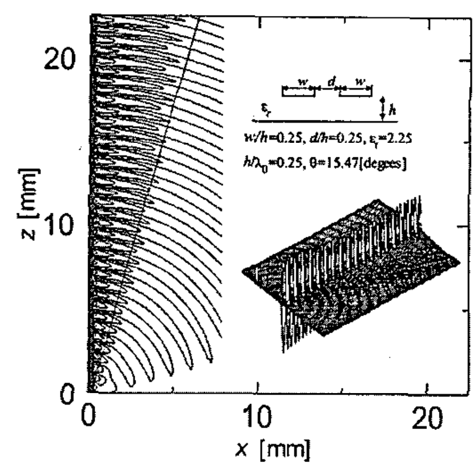


Fig. 3. Field-intensity distribution on the xy plane just below the air-dielectric substrate at $h/\lambda_0 = 0.25$.

LM$_2$ solution. The leakage direction of the field obtained by the FDTD calculation agrees very well with the theoretical leakage angle of the LM$_2$ solution. Figure 4 shows the field-intensity distribution at the normalized frequency $h/\lambda_0 = 0.26$. In this case, the field decay is also observed and the leakage angle is changed corresponding to the phase constant of the LM$_2$ solution. Furthermore we investigate the guide with another structural parameters (w/h = 0.25 and d/h = 0.50), of which the dispersion behavior is shown in Fig. 5. Figure 6 shows the field-amplitude variation just on the substrate along the center of the guide at the normalized frequency h/λ_0 = 0.28 marked ① in Fig. 5. In this frequency, the physical mode is only the bound mode, but the field decays again due to the contribution of the LM$_2$ solution. Therefore, we suspect from these results that the nonphysical LM$_2$ leaky solution has strong effect on the decay in the field-amplitude variation along the guide in the bound-mode region. In the next section, we verify this suspicion in another way.

III. Verification of Contribution of LM$_2$ Mode

We first extract the phase constant of the mode by applying the GPOF method to the field variation shown in Fig. 2(a). To minimize the extraction error, we use many sample-data sets of the field variation, which are obtained from different intervals along the z direction at different x and y positions. Each of the intervals is taken a little bit away from the excitation point, not to include the contribution of the unwanted wave due to excitation into the sample-data set. Figure 7(a) shows the extracted values (the circles) of the phase constant, where the horizontal axis N means the Nth sample-data set. The extracted values are very close to the values of the phase constant for the bound mode calculated by the SDM, which is indicated by the red line. Figure 7(b) show the extracted values obtained by applying the GPOF method to the field variation shown in Fig. 2(b). In this case, we can see the additional extracted values except for those corresponding to the bound mode. Although there is a periodicity and a certain deviation in these extracted values depending to the observation points, it is clear that they are near to the values of the phase constant for the nonphysical LM$_2$ mode by SDM, indicated by the blue line. It should be noted here that the extracted values from the FDTD data do not completely agree with the phase constant of the nonphysical LM$_2$ mode because its eigen modal field can not be excited by the practical source. This means that although the physical solution at this frequency is only the bound mode, the actual field slowly

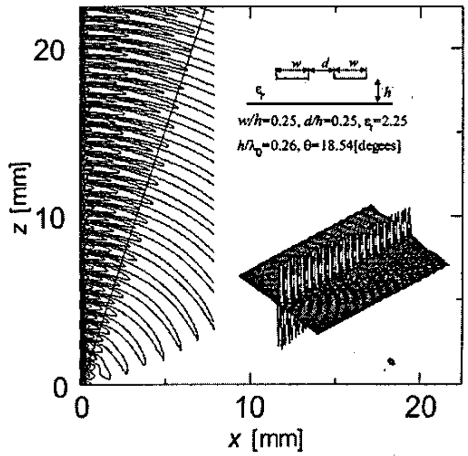


Fig. 4. Field-intensity distribution on the xy plane just below the air-dielectric substrate at $h/\lambda_0 = 0.26$.

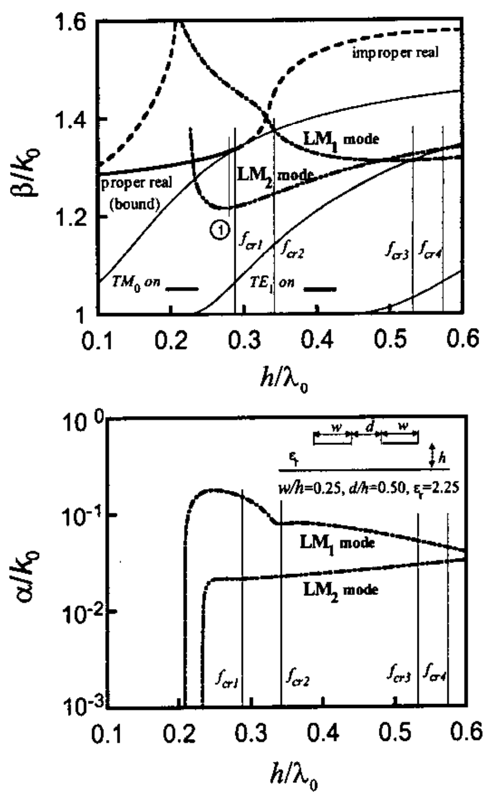


Fig. 5. Normalized phase and leakage constants for the conductor-backed coplanar strips for w/h = 0.25 and d/h = 0.50.

decays away from the source due to the indirect effect of the nonphysical LM_2 mode.

At the talk, we will present such a effect on other printed-circuit transmission lines and the experimental results to verify this effect.

IV. Conclusion

We have reported here that in the frequency range where the physical solution is only the bound mode, the actual field slowly decays away from the source due to the indirect effect of the nonphysical LM_2 mode. This effect has been proved by FDTD calculations.

Acknowledgement

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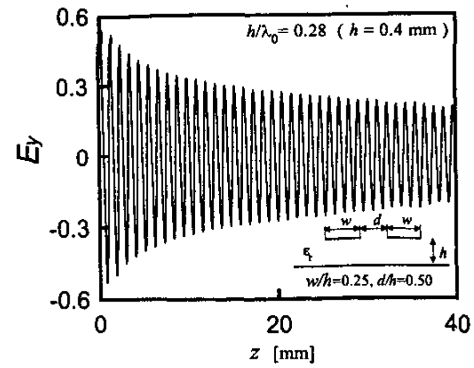
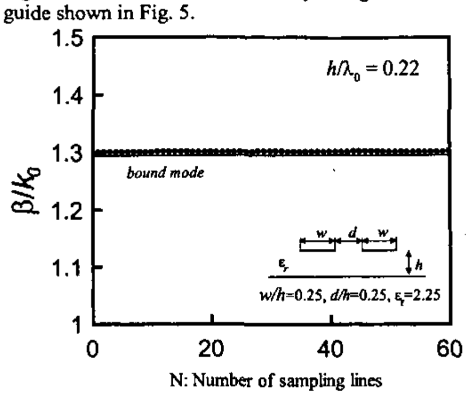
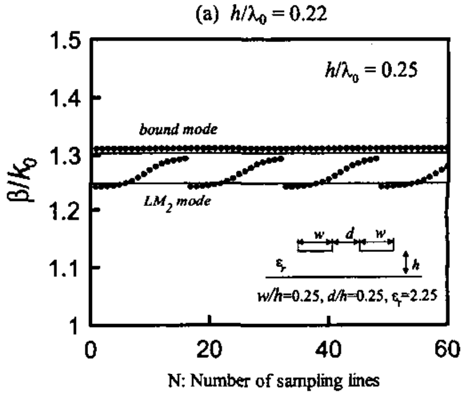


Fig. 6. Plot of the field-intensity along the center of the guide shown in Fig. 5.



(a) $h/\lambda_0 = 0.22$



(b) $h/\lambda_0 = 0.25$

Fig. 7. Matrix-pencil solutions extracted from the finite difference time domain (FDTD) data shown in Fig. 2.