UNEXPECTED CONTRIBUTION OF NONPHYSICAL MODE TO THE FIELDS EXCITED BY A PRACTICAL SOURCE IN PRINTED-CIRCUIT TRANSMISSION LINES

Mikio Tsuji, Hidehiro Takayama and Hiroshi Shigesawa

Department of Electronics, Doshisha University
Tatara-Miyakodani 1-3, Kyotanabe, Kyoto 610-0321, Japan

ABSTRACT

Contrary to ordinary belief, we report here for the first time that, on printed-circuit lines, some nonphysical solution (improper real solution in this paper) has a significant contribution to physical total fields excited by a practical source. Both the FDTD and GPOF methods numerically show the proofs.

I. INTRODUCTION

Under usual circumstances for printed-circuit transmission lines, the guided dominant mode is purely bound at lower frequencies and then becomes leaky above some critical frequency. At around this critical frequency, there exists the spectral gap, at which the bound-mode and the leaky-mode solutions are not connected smoothly each other, and both bound and leaky portions of the dominant mode are clearly separated from each other by the spectral gap. This critical frequency is given by the point where both dispersion curves for the dominant mode and the surface wave on the surrounding dielectric substrate cross each other. The physically meaningful solution appears as a bound mode above such a surface-wave, while as a leaky mode below this. Then, it has been understood so far that any practical field source excites only the modes corresponding to the physical solutions [1].

However, in our recent investigation relating to the excitation problems of narrow pulses in printed-circuit transmission lines, we have met with strange behavior of transmitted pulse [2]. It is hard to explain such behavior only by behaviors of the physical solutions. After careful examination, we have reached a conclusion that some of non-physical solutions may contribute significantly to the total fields. We prove here for the first time this important conclusion in two ways; by the total near-field calculation based on the FDTD method and by the extraction of the eigen values for both the physical and nonphysical modes by the Generalized Pencil Of Functions (GPOF) method [3].

II. CALCULATION RESULTS

We consider here the conductor-backed coplanar strips as an example of planar transmission lines, of which the normalized phase and leakage constants are shown in Fig. 1 [1]. As a first step, we select the strip width as w/h =0.375. The other dimensions and material constant are shown in the figure. Then, this guide exhibits the spectral gap between the frequencies f_{cr1} and f_{cr2} as seen, and the improper-real solution, that is nonphysical, turns back to low frequencies. For this guide, we discuss the excitation problem, using the FDTD method. As an excitation field, a monochromatic-frequency wave is considered, of which the field distribution is given the vector eigen function at that frequency on the guide cross section. Then, we calculate the plots of the field-intensity variation along the guide just below a strip. Figs. 2(a) and 2(b) show such plots at the normalized frequencies h/λ_0 = 0.35 and 0.40, respectively. It should be noted here that the leaky mode is the only physical mode at such high frequencies.

Let us next change the strip width w/h from 0.375 to 0.4482. Then the evolution of solutions changes as shown in Fig. 3. The significant change different from Fig. 1 is the behavior of the improper-real solution. This solution in the present case does not turn back to the lower frequencies, but now goes upward to higher frequencies. Both curves for the real solution and for the complex solution cross each other at a frequency, and the spectral gap disappears. The plots of the field intensity along this guide just below a strip are shown in Fig. 4. These plots have been done again at both

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

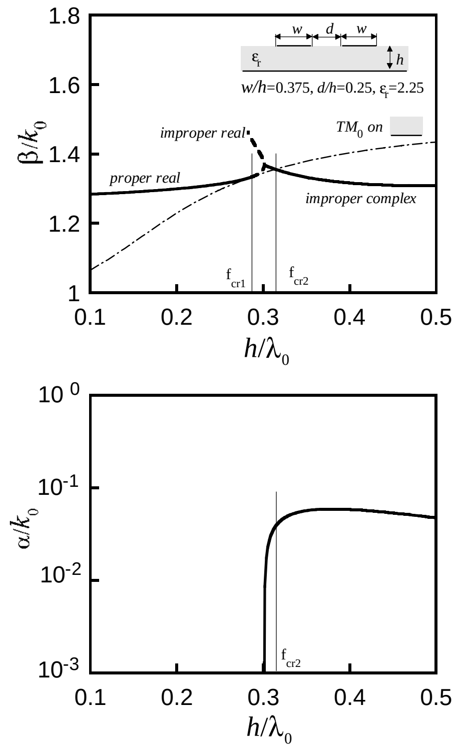

Fig. 1. The normalized phase and leakage constants for the conductor backed coplanar strips when the normalized strip width *w/h* is selected as 0.375.

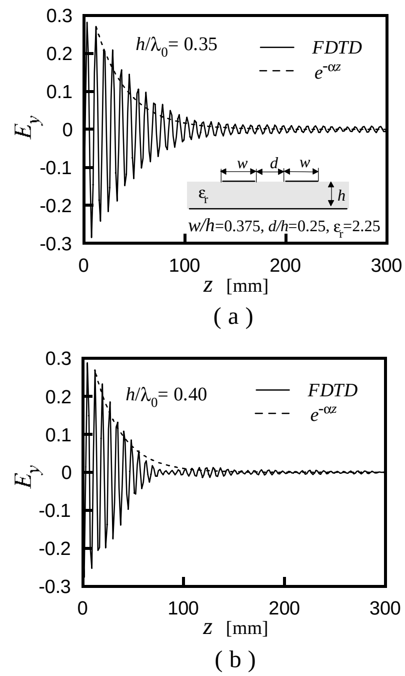

Fig. 2. The plots of the field-intensity variation along the guide of Fig. 1 just below a strip at the normalized frequencies (a) h/λ_0=0.35 and (b) 0.40. These field amplitudes decay exponentially with the leakage constant expected from the eigen value for α of Fig. 1.

frequencies h/λ_0 = 0.35 and 0.40. We should notice here that the physical mode is still only the leaky mode, though there exists the improper-real solution.

We further changed the strip width w/h from 0.4482 to 0.50 to modify the evolution of the improper-real solution as shown in Fig. 5. In this case, the situation of the simultaneous propagation of both the bound and the leaky dominant modes results between the frequencies f_{cr2} and f_{cr1}, but the improper-real solution also goes upward to higher frequencies almost touching the TM_0 surface-wave curve.

Fig. 6 shows the field-intensity plots along the guide at the guide central region calculated again at the frequencies h/λ_0 = 0.35 and 0.40. We can see in both results that the actual field decays very slowly along the guide, so that the field remains with remarkable amplitude even at a distance far away from the excitation source.

III. DISCUSSIONS

So far, we have shown the field-intensity behaviors along the guide for different three cases of the evolution of the improper-real solution.

Let us first look at Fig. 2. We find from those results that the field amplitudes decay exponentially with the leakage constant expected from the eigen value. Such a decaying feature is typical of the leaky mode in the range where such a leaky mode is the only physical solution (the frequency range above f_{cr2} shown in Fig. 1).

On other hand, Fig. 4 shows the results for the guide for which the spectral gap disappears as seen in Fig. 3, and the actual-field decay along the guide is now slower than that expected from the eigen value for α as seen in Fig. 4. So, the field remains with significant amplitude even at a distance away from the excitation source. Also, we notice that such a tendency appears significantly at lower frequency (h/λ_0 = 0.35) in the leakage range. Such behavior is beyond our expectation. Then our question is what the reasons for such behavior are. Of course, it is difficult to show conclusive reasons at present. However, we notice that the evolution of the improper-real solution is definitively different from that observed in Fig. 1 and we suspect that such a behavior is influenced somewhat by the improper-real solution.

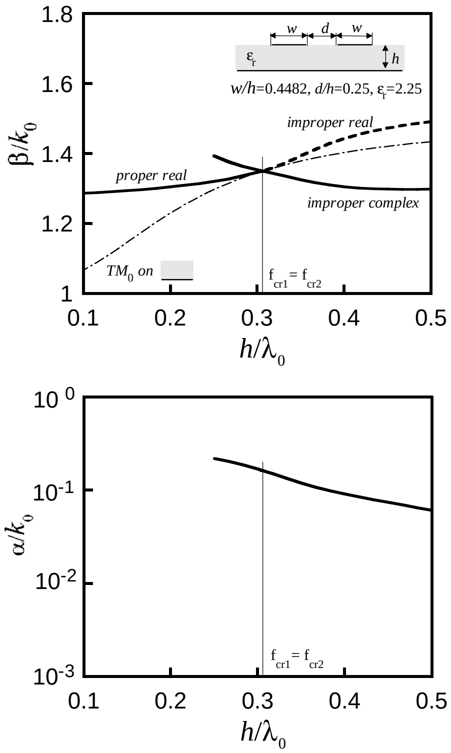

Fig. 3. The normalized phase and leakage constants for the conductor backed coplanar strips with *w/h* = 0.4482. In this case, the improper real solution goes upward to higher frequencies, and the spectral gap disappears.

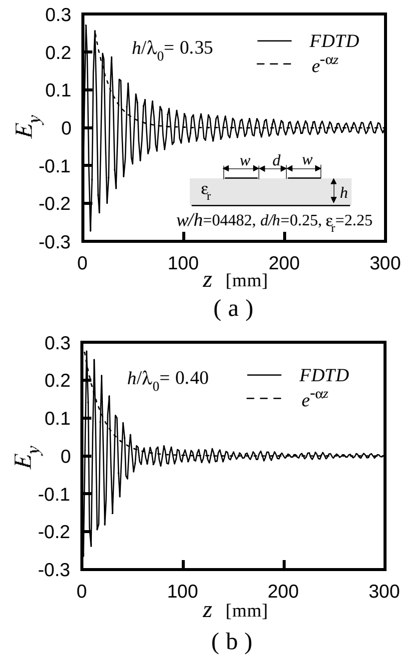

Fig. 4. The plots of the field-intensity variation along the guide of Fig. 3 just below a strip at the normalized frequencies (a) h/λ_0=0.35 and (b) 0.40. These field amplitudes decay exponentially with the leakage constant expected from the eigen value for α of Fig. 3.

To confirm this, let us here look at the field-intensity behavior only at the frequency h/λ_0 = 0.35. Then, we notice that the nonphysical improper-real solution is not observed at this frequency for the case of Fig. 1, while, for the cases of Fig. 3 and Fig. 5, the nonphysical improper-real solutions exist closely and more closely to the TM_0 surface-wave dispersion curve, respectively.

These results suggest us that the slow decay in the field-intensity variation along the guide depends strongly on how close the improper-real solution is to the TM_0 surface-wave curve, even if it is nonphysical. As a result, we conclude that such a nonphysical, improper-real solution can contribute significantly to the actual total field, when the field at the neighborhood of the strips (i.e., the near field) is discussed in the excitation problem.

To reinforce this conclusion, we have extracted the eigen values and the corresponding-wave amplitude (the magnitude of residues) from the field variation shown in Fig. 6(a) by the GPOF method. The results are shown in Table 1. The obtained eigen values are compared with those calculated by the spectral-domain method for both the physical, dominant leaky mode and the nonphysical improper-real mode. Both results show a reasonable agreement. Also, we find that the excitation intensity of the improper-real wave is significant. This point will be discussed in detail in the talk.

IV. CONCLUSIONS

We have reported here for the first time that some of nonphysical solutions (here the nonphysical, improper-real solution) contribute significantly to the total near fields. Such an important result in the field of the guided-wave theory has not appeared so far in the literature. So, we present here several evidence to prove this important conclusion in two ways; by the total near-field calculations based on the FDTD method and by the calculations of the modal amplitudes including both the physical and the nonphysical modes by the GPOF method.

To reinforce our discussions presented here, the relation between the integral path for the field representation and the actual locations of the nonphysical improper-real solution on the steepest-descent plane will be discussed in the talk. Also, at the talk, we will present some experimental proof that we are now going to take.

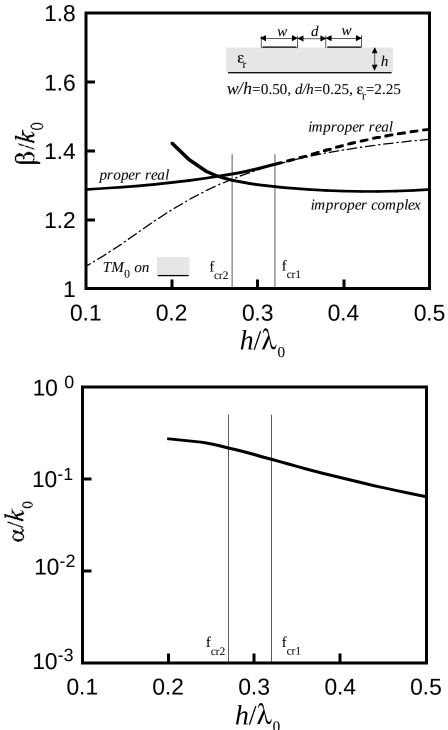

Fig. 5. The normalized phase and leakage constants for the conductor backed coplanar strips with w/h = 0.50. In this case, the situation of the simultaneous propagation results, and the improper real solution now goes upward to higher frequencies almost touching the TM_0 surface-wave curve.

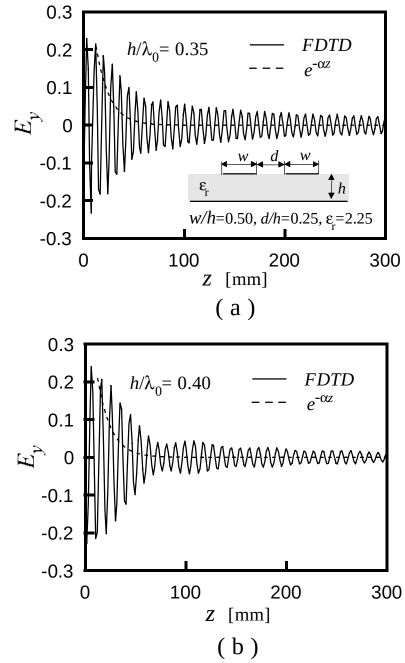

Fig. 6. The plots of the field-intensity variation along the guide of Fig. 5 just below a strip at the normalized frequencies (a) h/λ_0=0.35 and (b) 0.40. These field amplitudes now decay very slowly along the guide so that the fields remain with remarkable amplitude even at a distance far away from the excitation source.

Table 1. Extraction of the poles and amplitudes from the field plots of Fig. 6 (h/λ_0 = 0.40) by GPOF.

	SDM	GPOF	GPOF
improper mode	$\beta/k_0 - j\ \alpha/k_0$	$\beta/k_0 - j\ \alpha/k_0$	Amp. (relative)
complex	1.283 – j 0.103	1.264 – j 0.084	1.0
real	1.416 – j 0	1.414 – j 0.006	0.64

We have not discussed here the effect of a higher-order physical mode called the "Surface-Wave-Like (SWL)" mode. This mode that was first discovered by us on the coplanar waveguide with finite width was a bound physical mode in the lower frequencies [5]. Contrary to this, the SWL mode at present is physical, but leaky, of which the phase constant exists slightly above the dispersion curve of the TE_1 surface wave. So, the contribution of this mode to the total fields seems not to be significant in this paper. In the talk, however, discussions on the effect of this mode will be included.

ACKNOWLEGMENTS

This was supported in part by a Grant-in-Aid for General Scientific Research (09650432) from the Ministry of Education, Science and Culture of Japan and by the Grants from the Research Center for Advanced Science and Technology, Doshisha University.

REFERENCES

[1] C. Di Nallo, F. Mesa and D. R. Jackson, "Excitation of leaky modes on multi-layer strip line," Digest of IEEE/MTT-S IMS 1996, vol.1, pp.171-173, June 1996.

[2] M. Tsuji, H. Takayama and H. Shigesawa, "A new type of the narrow-pulse distortion caused by the simultaneous-propagation effect of both bound and leaky modes on printed-circuit transmission lines," Digest of IEEE/MTT-S IMS 1996, vol. 1, pp. 179-182, June 1996.

[3] Y. Hua and T. K. Sarkar, "Generalized pencil of functions method for extracting the poles of an electromagnetic system from its transient response," IEEE Trans. Antenna Propagat. vol. AP-37, pp.229-234, Feb. 1989.

[4] H. Shigesawa, M. Tsuji and A. A. Oliner, "Simultaneous propagation of bound and leaky dominant modes on printed-circuit lines; A new general effect," IEEE Trans. Microwave Theory Tech., vol. MTT-43, pp. 3007-3019, Dec. 1995.

[5] H. Shigesawa, M. Tsuji and A. A. Oliner, "A new mode-coupling effect on coplanar waveguides of finite width," Digest of IEEE/MTT-S IMS 1990, vol. 3, pp. 1063-1066, June 1990.