NEW INTERESTING LEAKAGE BEHAVIOR ON COPLANAR WAVEGUIDES OF FINITE AND INFINITE WIDTHS

Mikio Tsuji and Hiroshi Shigesawa
Department of Electronics
Doshisha University
Kyoto 602, Japan

and

Arthur A. Oliner
Department of Electrical Engineering
and Weber Research Institute
Polytechnic University
Brooklyn, New York 11201

Abstract

Last year we showed that coplanar waveguide leaks power in the form of a surface wave above some critical frequency, and that this leakage can cause undesirable cross talk and package effects. Further studies now reveal several new interesting behavioral features, including unexpected sharp minima and dimensional dependences.

1. Introduction

We have shown in previous work[1] that, when the frequency of operation is increased sufficiently, the dominant mode on conventional coplanar waveguide (CPW) becomes leaky instead of remaining purely bound, as had always been believed. This leakage of power occurs in the form of a surface wave on the surrounding substrate that travels away at an angle from the CPW itself. Such power leakage can, of course, result in cross talk with neighboring portions of the circuit, and it can produce unexpected package effects. It may therefore be important from a practical standpoint to understand when such leakage effects can occur and what their characteristics are.

We have recently studied these leakage effects in more detail, and we find several new interesting behavioral features. In this paper, we describe these new features, and we systematize them to indicate when the leakage effects are strong and when not, when interesting unexpected sharp and deep minima (cancellation effects) occur and how they depend on the structural parameters, and how the leakage behavior varies significantly when the CPW width changes from finite to infinite.

2. Background

The surface wave that leaks power is different when the CPW has finite or infinite width. These two structures are shown in Fig.1 with the dimensional notation to be used. The guides are of the conventional type, not conductor backed, and the difference between them is only that width c is infinite or finite. When c is infinite, the structure that surrounds the central guiding region is a dielectric layer of thickness h with a conducting plane on its top surface. The lowest surface wave that this surrounding structure can support is the TM_0 surface wave. When c is finite, the surrounding structure is a dielectric layer of the same thickness, but without any conducting plane, and the lowest surface wave it can support is the TE_0 surface wave.

The CPW dominant mode has relatively little dispersion, but the surface waves are strongly dispersive, with low values of β/k_0, the normalized phase constant, at low frequencies and with values approaching the index of refraction of the substrate at very high frequencies. At some frequency the dispersion curves for the CPW mode and the relevant surface wave mode cross each other. We have shown that at frequencies above this crossing the CPW dominant mode is no longer purely bound, but becomes leaky, with the power leaked away at an angle in the form of the lowest surface wave that can be supported by the surrounding structure. At still higher frequencies, crossings occur that involve the higher surface waves, with the result that power is

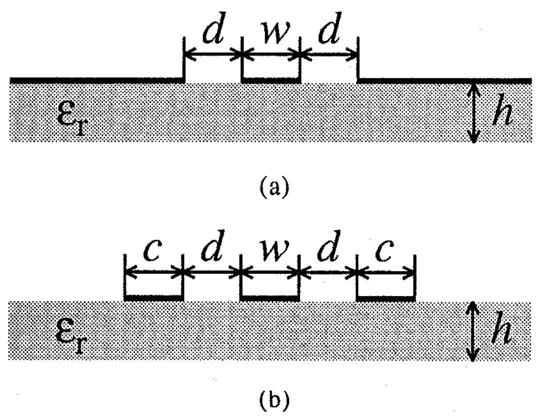

Fig.1 Cross-section views of conventional coplanar waveguide; (a) when the lateral width is infinite, and (b) when it is finite, with outer strips of width c.

S

also leaked into those surface waves as well. Concentrating now on only the behavior when leakage begins, we thus note that the power that is leaked occurs in the form of the TE_0 surface wave on an ungrounded dielectric layer when c is finite, and the TM_0 surface wave on a grounded dielectric layer of the same height (or thickness) when c is infinite. We observe not only that the surface waves are different but that the surrounding structures are different as well.

3. The New Leakage Properties

The new leakage studies that we have conducted recently shed important light on three behavioral features:

(a) the conditions under which the leakage rate is strong or weak,

(b) the significant modifications in leakage behavior that occur when the CPW width changes from finite to infinite, and

(c) the presence of unexpected sharp minima (cancellation effects) in the leakage rate.

Many of these new behavioral features are summarized in Fig.2, which presents the variations of the phase constant β and the leakage constant α, both normalized to the free space wavenumber k_0, as a function of h/λ_0, the height (or thickness) of the dielectric substrate relative to the free space wavelength. The curves are intended primarily to indicate the behavior of coplanar waveguide of finite width c, but for comparison the curves for infinite width are also included. The abscissa axis actually represents the variation with frequency, since h was held constant in the calculations.

We should first note that leakage occurs only at frequencies that are greater than the critical frequency at which the β/k_0 curve for the CPW dominant mode for the particular c/h value crosses the relevant surface wave curve. As indicated above, the relevant surface waves are the TE_0 surface wave

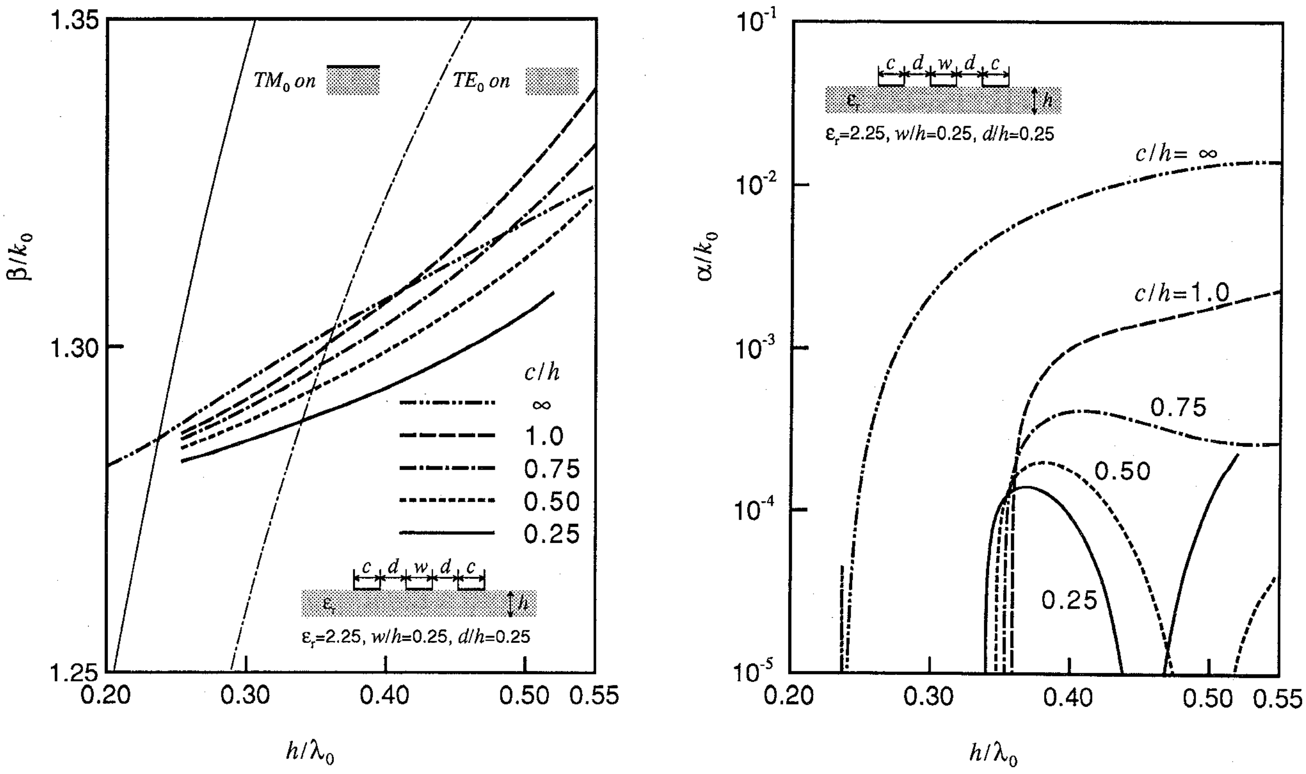

Fig.2. The behavior of the normalized phase constant β/k_0 and the normalized leakage constant α/k_0 of conventional coplanar waveguide of finite width as a function of frequency (in the normalized form h/λ_0). The outer strip width c is taken as the parameter, and results for the case of infinite width are included for comparison.

on an ungrounded dielectric layer when c is finite and the TM_0 surface wave on a grounded dielectric layer when c is infinite. The data in Fig.2 are seen to be consistent with these conditions.

The first new feature evident from Fig.2 is that the value of leakage rate α/k_0 varies considerably, with the leakage rate soon after the onset of leakage increasing with increasing guide width c. Note that the scale is logarithmic, so that the α/k_0 for c/h=1.0 is almost 10 times larger than that for c/h=0.25. Furthermore, the leakage rate for infinite width is seen to be almost 10 times larger than that for c/h=1.0, or almost two orders of magnitude larger than that for c/h=0.25.

The next evident new feature is the presence of sharp and deep minima in the curves for α/k_0 for c/h=0.25 and 0.50. We are still investigating the cause of these sharp drops, but we speculate now that they are cancellation or resonance effects caused by the excitation of an additional surface wave at the outer edges of the strips of width c. At the outer edges of the strips there is leakage of power outward in the form of the TE_0 surface wave on an ungrounded dielectric layer, since that is the structure of the surrounding substrate. At the same time, however, those edge discontinuities will also excite inward the TM_0 surface wave under the metallic strip of width c, and therefore under the complete CPW structure of finite width. This TM_0 mode will then propagate at some angle with respect to the guide axis between the two outer edges and become multiply reflected by them. For certain dimensions and frequencies a resonance can occur which would manifest itself in a cancellation effect and produce a sharp drop in the leakage rate.

The results shown in Fig.3 are concerned only with CPW of infinite width, where we see the effect of varying the width w of the metal center strip. In the β/k_0 plot, we observe the expected crossings with the surface wave curve. Interesting fine structure appears in the transition region in the immediate vicinity of the crossings, but we do not discuss those features here.

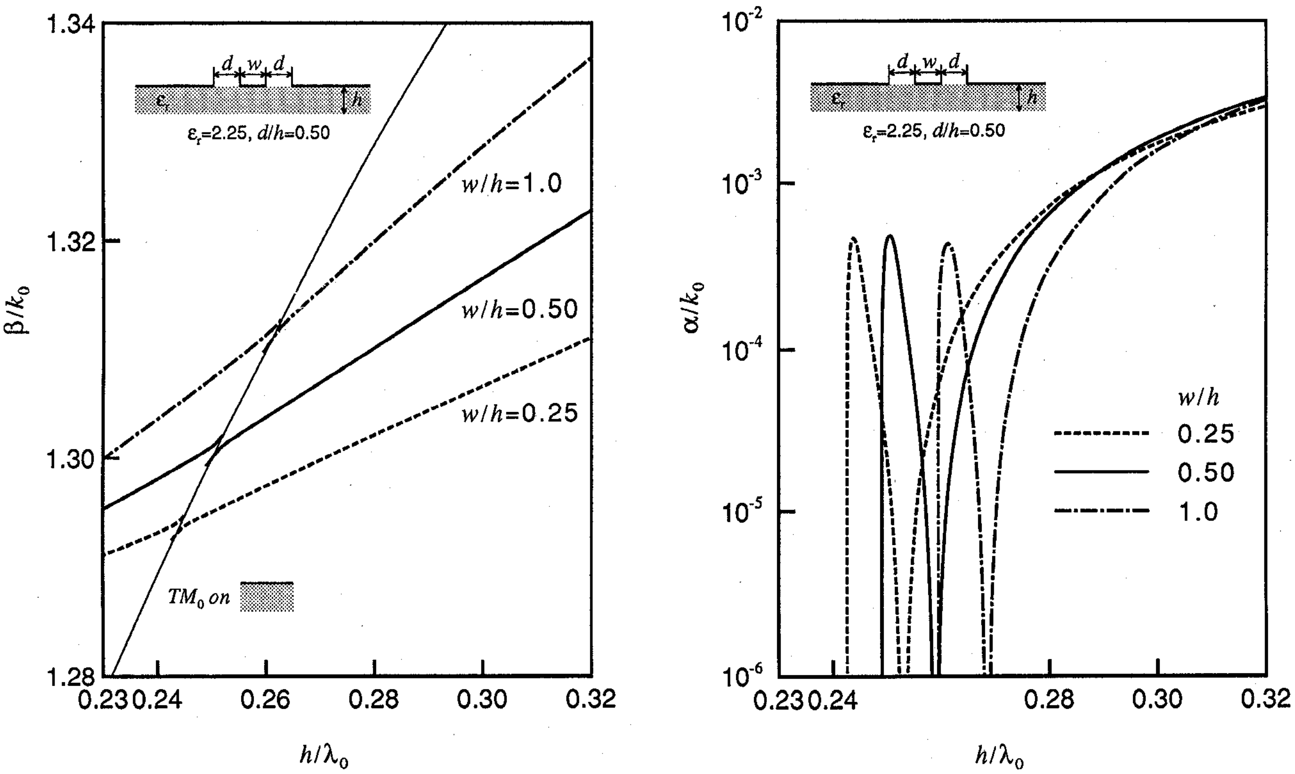

Fig.3. The behavior of β/k_0 and α/k_0 as a function of normalized frequency for conventional coplanar waveguide of infinite width. The normalized gap width d/h=0.50 for these curves, and the width w of the metal center strip is taken as the parameter. The sharp maximum and the sharp and deep minimum at the onset of leakage form the outstanding feature.

We concentrate in Fig.3 on the α/k_0 behavior, in particular on the narrow sharp minima and associated narrow sharp peaks that occur immediately after the onset of leakage. Note that the abscissa scale is an expanded one. At higher frequencies, as seen in Fig.2, the value of α/k_0 will exceed 10^{-2}, but in the range of these sharp peaks the values are less than 10^{-3}. By comparison with Fig.2, we see that the peaks when c is infinite are much narrower than the ones found when c is finite.

Examination of the α/k_0 plot in Fig.3 shows that when the width w of the central strip is varied the location of the peaks shifts, because the crossing with the surface wave curve occurs at a slightly different frequency. However, the widths and heights of the peaks and the widths of the minima are hardly changed at all.

The results shown in Fig.3 apply to the case for which the relative gap spacing d/h=0.50. When the gap spacing is reduced to d/h=0.25, we have found that the resulting changes in behavior are dramatic. Although the plots of those results are not shown here due to the limited available space, the sharp peaks in α/k_0 have become much narrower, and the magnitudes at the peaks are a decade smaller. Furthermore, changing w/h again only shifts the location of the peaks but affects the other features in only a minimal way. It is therefore clear that with respect to these sharp peaks and minima the central strip width plays a negligible role whereas the value of gap width strongly affects the properties of these peaks and minima.

4. Conclusions

When the frequency of operation of a circuit that utilizes coplanar waveguide is increased sufficiently, leakage of power away from the waveguide occurs in the form of a surface wave. This power leakage can cause unwanted cross talk between neighboring portions of the circuit and produce unexpected package effects. It is therefore important to understand the characteristics of such leakage and its dependence on the dimensional parameters.

Our recent studies of these leakage properties have revealed a number of new behavioral features that are both important from a practical standpoint and interesting on fundamental grounds. Some of the conclusions to be drawn from these studies are the following.

(a) The leakage rate (the power leaked per unit length along the guiding structure) can vary considerably, depending on the frequency and the dimensional parameters. In the frequency region soon after the onset of leakage, it is found that the leakage rate increases substantially as the width c of the CPW is increased. Furthermore, when the CPW has infinite width the leakage rate is higher than that for any finite width value.

(b) When the width c is finite, the widths w of the central metal strip region and d of the gap regions play a secondary role in the leakage properties, whereas the width c of the outer strips plays a strong role. When the width c is infinite, changes in the gap width d influence the leakage behavior significantly but the value of metal strip width w affects the behavior minimally.

(c) For CPW of finite width, we found the presence of sharp and deep minima in the leakage rate at specific combinations of frequency and outer strip width c. We have proposed an explanation for these sharp minima in terms of a cancellation effect due to the excitation of another surface wave that is multiply reflected between the outer edges of the CPW of finite width.

(d) When the CPW has infinite width, sharp and deep minima also occur but their properties are different. The maxima associated with them are also very narrow, in contrast to the case when c is finite, and these effects occur only immediately after the onset of leakage.

(e) As the frequency increases further, other surface waves contribute to the leakage. The transition regions that occurs at the onset of these additional contributions are both unusual and very interesting, and we are looking further into their characteristics.

Acknowledgment

This work was supported partly by the Ministry of Education, Science and Culture of Japan under a Grant-in-Aid(63550261) for General Scientific Research.

References

[1] H.Shigesawa, M.Tsuji and A.A.Oliner,"Power leakage from the dominant mode on coplanar waveguides with finite or infinite width," 1990 URSI Radio Science Meeting Abst., p.340, May 1990.