A NEW MODE-COUPLING EFFECT ON COPLANAR WAVEGUIDES OF FINITE WIDTH

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Abstract

A new mode-coupling effect that occurs on conventional coplanar waveguides of finite width is identified and explained here for the first time. The coupling occurs between the standard CPW dominant mode and a new dominant mode also identified here for the first time, and called here the CPW dominant surface-wave-like mode. This coupling is different from that which is known to occur when a printed-circuit waveguide is placed in a box or package; here there is no box, and the finite width by itself is sufficient to produce the coupling effect. Other new physical effects, that will be discussed in detail elsewhere, are included here in order to place the new coupling effect in perspective.

1. Introduction

We report here a new mode-coupling effect that occurs on coplanar waveguides of finite width. This coupling, which involves the dominant mode, has not been recognized before in the literature, nor has attention been paid to the newly identified mode that causes the coupling.

It has been appreciated that modes on printed-circuit waveguides (of which coplanar waveguide of finite width is one example) can interact with the modes of the box or package in which they are placed, and that this interaction will produce mode-coupling effects. The significant difference in the present work is that the coupling effect occurs even though no box or package is introduced. The finite width ***by itself*** is enough to produce a coupling effect, and it is this feature that is particularly interesting.

Conventional (not conductor-backed) coplanar waveguide of finite width, which is shown in cross section in Fig.1, consists of three conductors, so that it possesses two dominant modes of open-circuit-bisection symmetry. One of these is the standard, well-known coplanar waveguide dominant mode whose electric field is sketched roughly in Fig.2(a). The other dominant mode is the one shown in Fig.2(b). This second mode is new in the sense that it has not been identified or discussed previously in the literature. However, the counterpart of this new mode when the coplanar waveguide is conductor backed has been discussed by us [1] and independently by R.W.Jackson [2], and was described further in [3]. That mode was called " microstrip-like " because there was a bottom conductor. Here, in Fig.2(b), the mode is a type of surface wave on a structure composed of a dielectric layer on which the ground plane is of finite width, and has gaps in the metal. We are therefore calling this new mode the " CPW surface-wave-like mode."

The standard CPW dominant mode is only slightly dispersive, but the CPW surface-wave-like mode is highly dispersive, having a lower propagation wavenumber β than the other mode at lower frequencies and a higher value of β at higher frequencies, so that their dispersion curves cross at some frequency. The coupling effect occurs where they cross, of course.

We have made calculations of the properties of this new mode, and of the new coupling effect, for several different geometrical cases and for two different values of dielectric constant. The next section contains some samples from those calculations.

When the width c of the outer plates of coplanar waveguide become infinite, we have shown

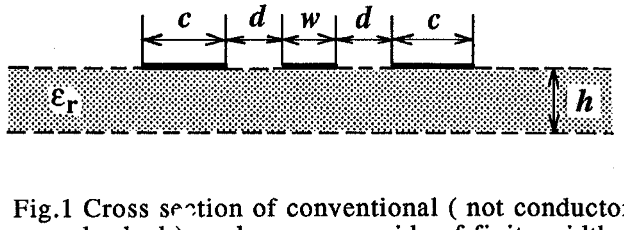

Fig.1 Cross section of conventional (not conductor-backed) coplanar waveguide of finite width c.

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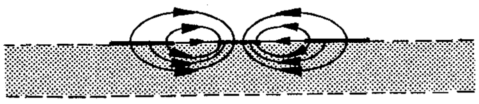
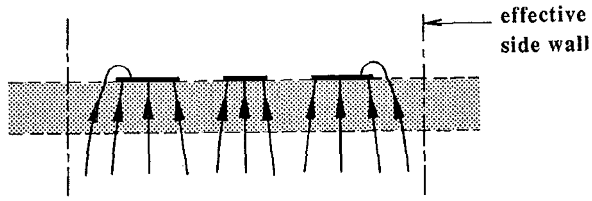


(a) Standard mode



(b) New mode

Fig.2 Sketches of the electric field distributions of the two dominant modes with open-circuit-bisection symmetry of coplanar waveguide of finite width. (a) The standard CPW dominant mode; (b) The new CPW dominant mode identified here, called the "surface-wave-like mode."

in [4] that, above a certain frequency, leakage of power occurs at some angle under the plates in the form of the TM_0 surface wave on the grounded dielectric layer. We have also shown that when plate width c is finite, but the dielectric layer continues onward laterally, leakage can also occur (usually beginning at a higher frequency) on the ungrounded dielectric layer in the form of the TE_0 surface wave, and later the TM_0 surface wave also, on that layer. For frequencies above the critical frequencies at which these leakage effects begin to occur, substantial changes appear in the nature of the fields of the standard CPW dominant mode.

The new coupling effect discussed here, on the other hand, occurs at a frequency that is usually somewhat ***lower*** than these leakage critical frequencies. In order to place this new coupling effect in perspective with respect to these other basic behavioral features of the CPW dominant mode as a function of frequency, we are also including on each figure the curves that indicate when leakage of each type begins.

2. Typical Results

(a) *The CPW Surface-Wave-Like Mode*

As mentioned above, the coplanar waveguide of finite width possesses three conductors, so that another dominant mode is present that has the same basic symmetry with respect to the bisection plane as the standard CPW dominant mode. This second dominant mode is newly identified by us here, and is being called the CPW surface-wave-like mode.

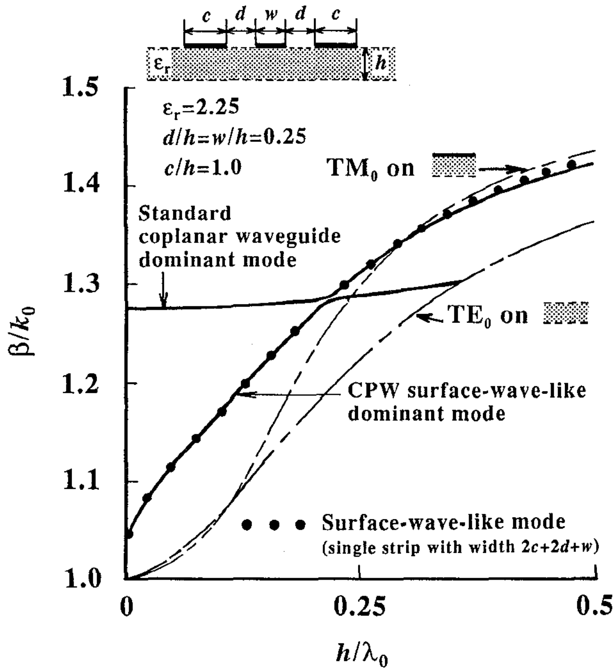


Fig.3 Dispersion behavior of various modes, illustrating the new mode-coupling effect. The coupling occurs between the standard coplanar waveguide dominant mode and the CPW surface-wave-like dominant mode. The solid dots represent an approximation to the CPW surface-wave-like dominant mode. The significance of the auxiliary curves (shown broken) for the TM_0 surface wave on a grounded dielectric layer and the TE_0 surface wave on an ungrounded dielectric layer of the same height is explained in the text.

Sketches of the electric field lines of these two dominant modes are shown in Fig.2. The new mode, which appears in Fig.2(b), is seen to be a surface wave of finite width on a structure consisting of a dielectric layer under a peculiar metal ground plane, since it is of finite width and has gaps in it.

This new mode is highly dispersive, and an example of its dispersion behavior is shown in Fig.3. In that guiding structure, the value of ε_r is low, being equal to 2.25, and the relative structural dimensions are fairly typical. Superimposed on the solid line we may observe a series of solid dots. Those dots correspond to the β/k_0 values obtained when the gaps in the ground plane are filled in, that is, when the ground plane becomes a single metal strip of width $(2c+2d+w)$. It is seen that the gaps in the ground plane have very little effect on the behavior of this new mode; it appears only to lower the β values very slightly at the higher frequencies. Similar very close correspondence was found for other geometrical parameter values.

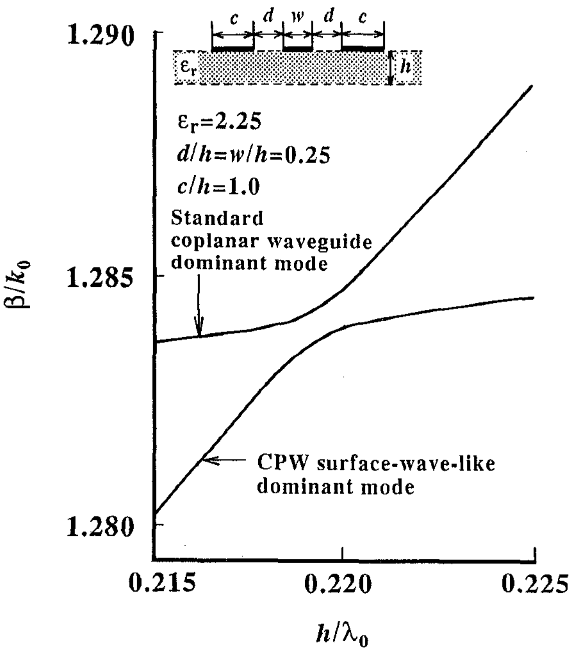


Fig.4 The coupling region itself from Fig.3 plotted on a greatly expanded scale, showing that the coupling behavior is of the classical " directional coupler " co-flow type.

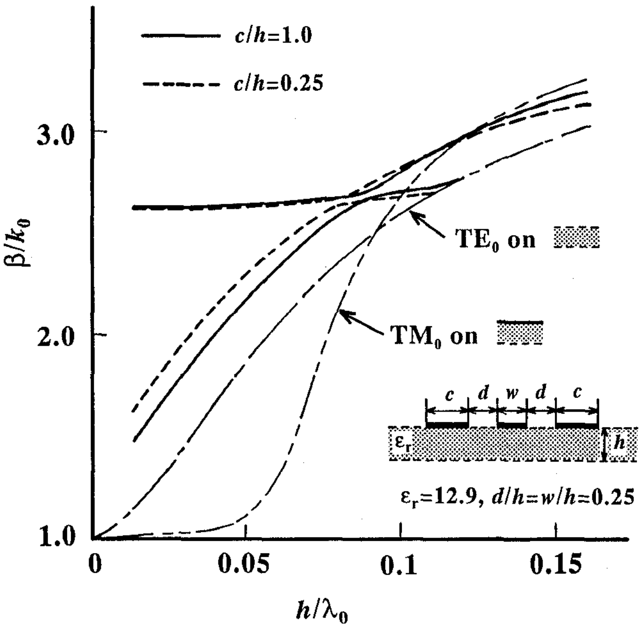


Fig.5 Dispersion plots of the type shown in Fig.3, but for ε_r = 12.9 instead of 2.25. Results are presented for two different values of outer plate width c. The coupling regions are wider here than those in Fig.3 for reasons given in the text.

(b) *The New Coupling Effect*

The coupling effect appears where the new dominant mode crosses the standard dominant mode in the dispersion plot. In Fig.3, the coupling effect is seen to be very sharp. The coupling region itself is replotted in Fig.4 on an expanded scale, where it is seen that the behavior is of the classical "directional coupler" co-flow type.

The coupling region is so narrow because the fields of the two modes involved are not very similar to each other. As a result, the interaction is not strong. The rough sketches of the electric fields of the two modes shown in Fig.2 are sufficient to indicate that these fields are in the main different from each other. We have also obtained detailed field-vector plots of the electric field in the cross section that offer a clearer picture, but they are not included here due to space limitations.

Other relative dimensions result in significantly wider coupling regions. For example, calculations show that the coupling region becomes wider when c/h is made smaller, consistent with the fact that in a relative sense the field of the standard mode is less concentrated in the central region alone. The coupling region also becomes wider when the dielectric constant of the substrate is increased. More of the field of the standard CPW mode is then in the dielectric region, and the field of the surface-wave-like mode, which is already predominantly in the dielectric region, is also more strongly drawn into the dielectric region. The interaction between the modes therefore increases somewhat, resulting in a wider coupling region, as seen in Fig.5.

Two cases are described by Fig.5, both for ε_r= 12.9 (instead of 2.25, as in Figs.3 and 4), but for different values of metal plate width c. The coupling widths for the two cases are roughly the same (and are much larger than the width seen in Fig.3), but the coupling occurs at a lower frequency for the narrower plate width c. Other calculations bear out this behavior.

On both Figs.3 and 5 two other curves are shown, one labeled TM_0 and the other TE_0. As indicated in the Introduction, these curves are included because they mark the boundaries that characterize different behavior regions for the standard CPW dominant mode.

When the width c of the outer plates becomes infinite, it can be shown that leakage of power occurs at some angle under the plates in the form of the TM_0 surface wave on the grounded dielectric layer, provided that the frequency is above some critical frequency. That critical frequency occurs when the dispersion curve for the standard CPW mode crosses the curve for the TM_0 surface wave on the grounded dielectric layer. If the outer plate width c is not infinite but finite, as in our case, the surface wave can still become excited but it gets reflected back from the outer sides of the plates instead of leaking away. The propagation wavenumber then remains real, but the modal field changes character since there is now some additional field, in the form of a surface wave, under the outer plates. The change in the field will depend on the value of the leakage constant in the $c = \infty$ case; a small leakage constant would correspond to only a minor change in the field under the plates.

Inspection of Figs.3 and 5 reveals that the coupling regions for those cases occur at a frequency ***lower*** than that for the crossing with the TM_0 mode. For a different set of parameters the coupling can occur at a higher frequency, and an example will be presented in the talk.

We next comment on the significance of the TE_0 curve in these figures. It can also be shown that, when the plate width c is finite but the dielectric layer continues onward laterally, leakage can also occur above a certain frequency on the dielectric layer outside of the plate region in the form of the TE_0 surface wave. At a somewhat higher frequency, leakage into the TM_0 surface wave can also occur. If the dielectric layer is transversely unbounded, the propagation wavenumber becomes complex. Of course, this leakage effect occurs for frequencies greater than the critical one at which the curve for the standard CPW mode crosses the curve for the TE_0 mode. In Figs.3 and 5, this frequency is higher than that for the field change under the plates, discussed just above. The curves for the standard CPW mode in these two figures are also shown terminated when they reach the TE_0 curves, indicating that beyond that point the solutions are no longer real.

3. Conclusions

It has been shown in this paper for the first time that the standard CPW mode changes its character as the frequency is increased. When the outer plates are finite in width but the dielectric layer continues laterally, this mode behaves as generally understood at lower frequencies, that is, the field is closely bound to the central region, and the mode is only slightly dispersive. As the frequency is increased, a ***coupling*** occurs to another dominant mode on the CPW structure. Both this coupling effect and the mode that causes it are identified in this paper for the first time. The new mode is being called the CPW surface-wave-like mode.

When the frequency is increased further, the curve for the standard CPW mode crosses the curve for the TM_0 surface wave on a ***grounded*** dielectric layer. For frequencies higher than the one for that crossing, some ***additional field*** in the form of the TM_0 surface wave exists under the outer plates of width c. There may be a large amount or only a small amount of added field, depending on conditions.

When the frequency is increased still further, the curve for the standard CPW mode crosses the curve for the TE_0 surface wave on the ***ungrounded*** dielectric layer. For frequencies above the one corresponding to that crossing, ***leakage*** away from the plates at an angle to them occurs on the dielectric layer in the form of the TE_0 surface wave. The propagation wavenumber for the standard CPW mode then becomes ***complex***, consistent with the leakage effect.

The various curves that define these ranges of behavior are indicated in Figs.3 and 5. It is important to note that the TM_0 and TE_0 surface wave curves shown there apply to different structures; the TM_0 curve corresponds to a grounded dielectric layer of height h, whereas the TE_0 curve corresponds to an ungrounded dielectric layer of the same height. Although the prime purpose of this paper is to identify and explain the new coupling effect, the other curves (and their physical significance) are included in order to place the new coupling effect into perspective with respect to other effects that can occur at these higher frequencies.

Acknowledgement

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