M-3

MODE PROPAGATION IN LATERALLY BOUNDED CONDUCTOR-BACKED COPLANAR WAVEGUIDES

Giorgio Leuzzi+, Agnes Silbermann++ and Roberto Sorrentino+

+ Istituto di Elettronica, Universita' di Roma, Via Eudossiana 18, 00184 Roma, Italy

++ Elettronica S.p.a., Via Tiburtina, Roma, Italy

ABSTRACT The propagation characteristics and field distributions in conductor-backed coplanar waveguide are investigated using a full-wave technique. The influence of the lateral boundaries of the structure is illustrated in detail. With respect to the unbounded structure additional modes can propagated even in the low-frequency range.

1. Introduction

Recent developments of GaAs monolithic microwave integrated circuits (MMIC) have stimulated a number of theoretical analyses of various configurations of planar transmission lines suitable for such applications.

Shih and Itoh [1] have analyzed the propagation of the dominant quasi-TEM mode in a modified version of the coplanar waveguide: the conductor-backed coplanar waveguide (CBCPW). An additional ground plane on the back of the substrate is useful to provide a sufficient mechanical strength to the GaAs circuit. In their work, Shih and Itoh applied the spectral domain technique to the analysis of a CBCPW having an infinite lateral extent. In actual cases, however, the limited extent of the structure can give rise to phenomena which modify the propagation characteristics of the trans-mission line.

In this work, making use of a general method recently developed for analyzing printed circuit transmission lines for MMIC [2], the effects of the limited extent of the CBCPW are investigated. It is pointed out, in particular, that, with respect to the standard CPW, additional modes can propagate in the structure, even in the low frequency range.

2. Method of analysis

The geometry of a CBCPW is shown in Fig.1. This structure can be analyzed by a mode matching technique. The method used in [2], which is basically a modification of that developed by Cohn for the slot line [3], requires the insertion of two longitudinal electric or magnetic walls perpendicular to the substrate at some distance D from the center of the structure. For symmetry considerations, a further longitudinal magnetic (even modes) or electric (odd modes) wall can be placed at the center of the metallic strip.

These side walls can be used to represent the actual lateral boundaries of practical structures. Depending whether the top planes are electrically connected to the back plane or not, the more appropriate choice of the lateral walls will be that of electric or magnetic planes respectively.

In the absence of the back metallization, as in a standard CPW, the lateral walls are sufficiently apart from the center of the structure so that they have a negligible effect on the field distribution, mainly concentrated in the proximity of the slots. In the present case, on the contrary, because of the back metallic plane, the lateral walls, even if placed at a large distance from the slots, can strongly interact with the electromagnetic field guided by the coplanar structure, so as to modify its propagation characteristics.

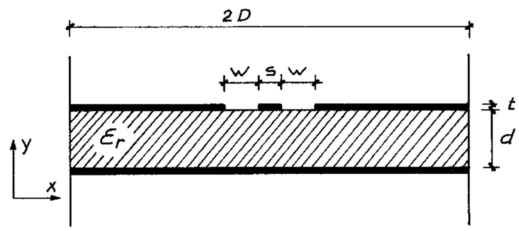

Fig.1. Geometry of the CBCPW

The lateral boundaries together with the symmetry plane reduce the structure, as seen toward the y-direction, to a parallel-plate waveguide (PPW) loaded with a metallic iris and a dielectric slab short circuited at one end. Because of its finite thickness, the iris itself may be regarded as a PPW section. In this way, the whole structure can be divided into three regions: the air region, the iris (or slot) region and the dielectric substrate region. The EM field can be expressed as a series expansion in terms of TE and TM (with respect to y) modes in each region. The boundary conditions yield to a homogeneous system of equations in the expansion coefficients; the condition for non-trivial solutions leads to a complex trascendental equation in the propagation constant β_g in the z-direction. By a proper manipulation, the number of unknowns can be reduced to 4xN-2, corresponding to the wave amplitudes of the EM field inside the iris region, N being the number of terms used in the field expansion in this region.

3. Results

Fig.2 shows a typical plot of the computed normalized phase constant β_g/β_o of the modes in a CBCPW laterally bounded by two conducting walls 5 mm apart from the center of the structure. For comparison, the behaviors of β_g/β_o of the same coplanar structure without the back conductor and of the unbounded CBCPW [1] are shown.

In the low-frequency range, the bounded CBCPW supports the propagation of a quasi-TEM mode having zero cutoff frequency. With respect to the standard CPW, this mode has a higher phase constant, thus a higher effective

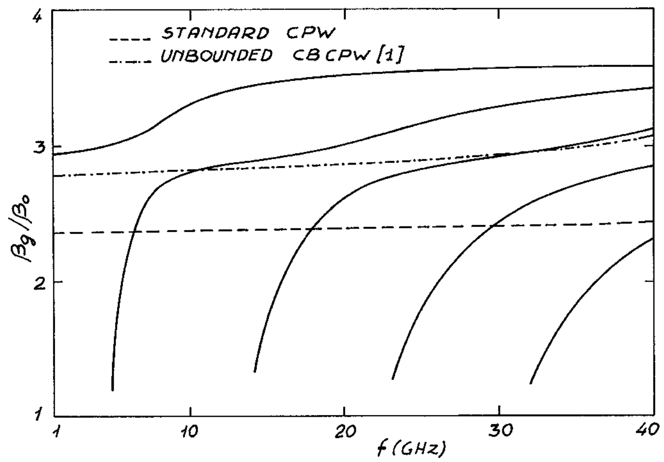

Fig.2. Dispersion properties of a CBCPW bounded by electric walls with s=100 μm, w=200 μm, d=150 μm, ε_r=13, t=1 μm, D=5mm.

permittivity; the back conductor, in fact, has the effect of increasing the electric field lines passing through the dielectric substrate. As the frequency increases, higher order modes can propagate in the structure; it could be seen that their cutoff frequencies depend on the distance between the lateral walls. It is noted that the phase constant of the dominant mode undergoes a notable increase

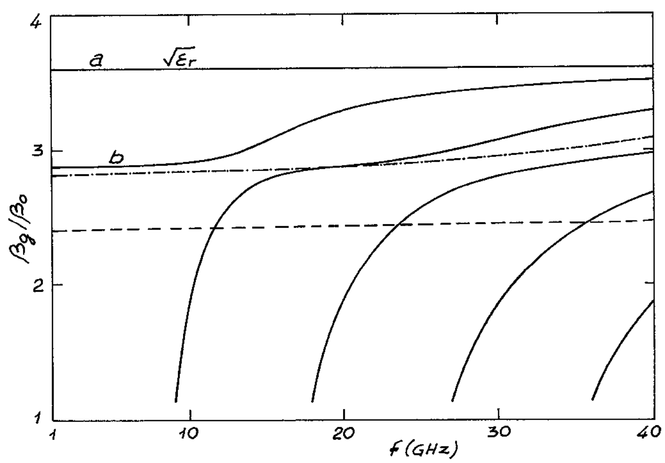

Fig.3. Same as Fig.2 except with magnetic walls

at frequencies close to the cutoff of the first higher order mode. As will be shown below, this phenomenon is related to a change in the field distribution of the dominant mode.

If the back metallic plane is not electrically connected to the top ground planes, two quasi-TEM modes can propagate in the CBCPW. These modes correspond to the two electrostatic fields which are obtained by putting at equal or different potentials the strip conductor and the top planes. This is illustrated in Fig.3 where the computed values of β_g/β_o are shown for the same CBCPW but laterally bounded by two magnetic walls. It could be seen that the mode 'a' with higher β_g, thus higher ε_{eff}, has a field distribution which is practically the same as that of a parallel-plate waveguide, slightly perturbed by the presence of two slots in the top conductor. For this mode, in fact, $\varepsilon_{eff} = \varepsilon_r$ at all frequencies.

Apart from this further mode the results in Fig.3 are close to those in Fig.2 except for a shift in the cutoff frequencies of the higher modes, which is due to the different boundary conditions at the side walls.

The existence of higher order modes in the bounded CBCPW can be easily understood observing that the structure can be regarded as a rectangular waveguide having two longitudinal slots in the top conducting wall, so that there is a close correspondence between the cutoff frequencies of the bounded CBCPW and those of a rectangular waveguide having the same dimensions.

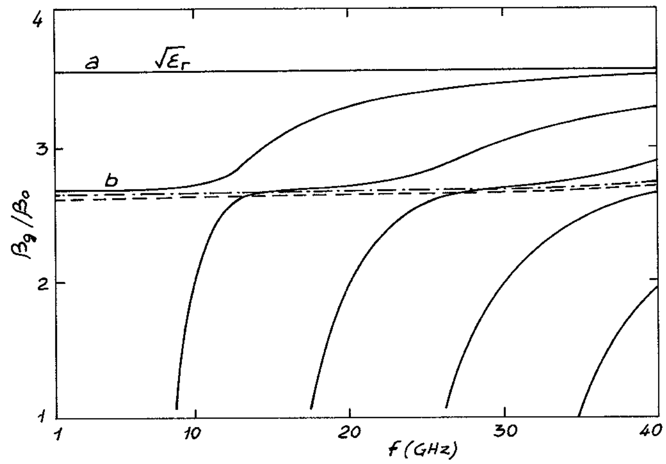

Fig.4 . Same as Fig.3 except for d=500 m.

The effect of the back conductor on the dispersion properties of the CPW is less pronounced the thicker is the substrate; this is shown in Fig.4, relevant to a bounded CBCPW with a thicker dielectric substrate. It is seen that the cutoff frequencies of the higher modes are practically unaffected by the substrate thickness, since they depend on the distance between the lateral walls.

All the structures considered have a very narrow slot width; in such cases a good accuracy of the theoretical results is obtained using only the first term, corresponding to the zero-order TE mode, of the field expansion in the slot region.This means that all the modes have practically the same field distribution inside the slot, but they may have different field distributions inside the dielectric substrate.The only exception is the 'a' quasi-TEM mode, for which at least two terms are required in the field expansion inside the slot. Since this mode is obtained by putting the strip conductor at the same potential of the top planes, in fact, the E_x field inside the slot has a null zero order component.

In order to gain a physical insight into the mode propagation in the CBCPW, the field distribution inside the structure has been computed. The electric field component E_y of the 'b' mode and of the first higher mode of the same structure considered in Fig.3 are plotted as a function of x in Fig.5 a,b at different frequencies. All the field components have been normalized to their maximum amplitudes. It can be noted that the field distributions result from the superposition of a CPW mode guided by the strip conductor and of rectangular waveguide modes which are guided by the metallic planes. For each mode of the bounded CBCPW there is a frequency range where the field is confined to the proximity of the strip; in such a case the phase constant of the mode is practically coincident with that of the unbounded structure (see Figs.2-4). In particular, the 'b' mode has a confined field distribution in the low-frequency range: as the frequency approaches the cutoff of the first higher mode, the field is spread out up to the lateral boundaries. Correspondingly, the effective permittivity of the mode is increased, since the electric field lines are more confined to the substrate dielectric.

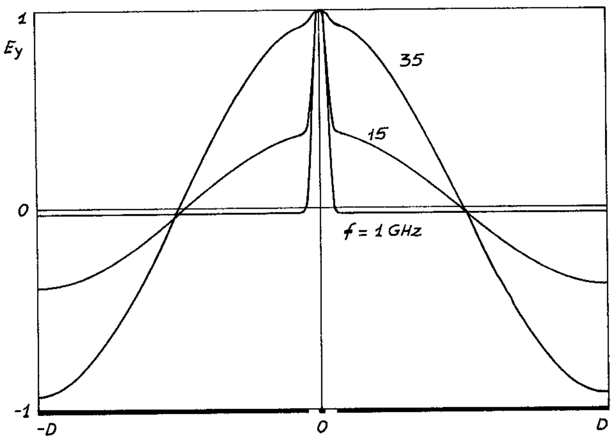

Fig.5a . E_y-field distribution of the 'b' mode of Fig.3

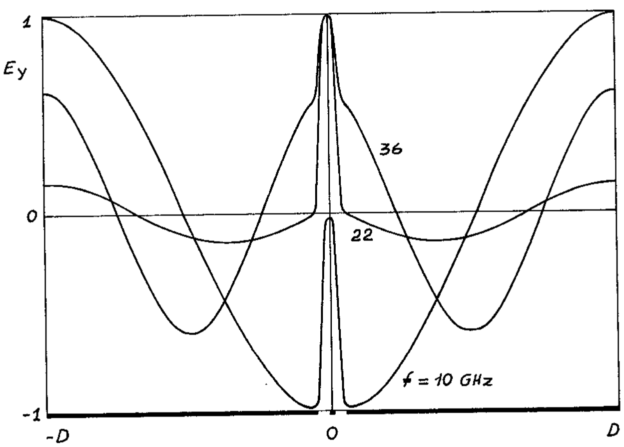

Fig.5b . E_y-field distribution of the first higher order mode of Fig.3.

With regard to the E_x and E_z components of the electric field, computations have shown that their distributions are practically the same for all the modes (except the 'a' mode) and are confined to the proximity of the slots. This is consistent with the fact that the waveguide modes have null E_x and E_z components.

The comparison between the present results and those by Shih and Itoh [1] for the unbounded CBCPW, illustrated in Figs.2-4, shows that their computed values agree well with the present ones as long as the field is concentrated in the proximity of the strip, i.e. is actually guided by it, though it could corresponds to different modes of propagation of the bounded structure. In the proximity of some critical frequencies, on the contrary, the field strongly interacts with the lateral boundaries and a waveguide mode is excited so that the propagation characteristics are notably modified.

4. Conclusions.

A full-wave analysis based on a mode-matching technique has shown that the limited extent of conductor-baked CPW's can notably alter the propagation characteristics of the structure. Depending on the type and distance of the lateral walls, higher order modes with finite cutoff frequencies can propagate. Moreover, if the top planes are not electrically connected to the back plane, two quasi-TEM modes can be supported by the structure. The analysis of the field distribution has shown that the propagation characteristics of the bounded structure are close to those of the unbounded one as long as the field is confined to the strip conductor, while, in the proximity of some critical frequencies, the field strongly interacts with the lateral boundaries and the propagation constants are modified.

5. References

[1] Y.C.Shih, T.Itoh,"Analysis of conductor-backed coplanar waveguide", Electron. Lett., vol.18, n.18, pp. 538-540, June 1982.

[2] R.Sorrentino, G.Leuzzi,"Full-wave analysis of integrated transmission lines on layered lossy media", Electron. Lett., vol.18, n.14, pp.607-608, July 1982.

[3] S.B.Cohn,"Slot line on a dielectric substrate",IEEE Trans. M.T.T., vol.MTT-17, pp.768-778, Oct. 1969.