Effect of Finite-Width Backside Plane on Overmoded Conductor-Backed Coplanar Waveguide

Ching-Cheng Tien, Ching-Kuang C. Tzuang, and S. T. Peng

Abstract— **The full-wave mode-matching method is utilized to investigate the transmission characteristics of a conductor-backed coplanar waveguide (CBCPW) with a finite backside plane. Experimental results of the scattering parameters of the CBCPW through line are presented. The theoretical results of the proposed CBCPW model, which consider a finite backside-plane CBCPW to be a system of coupled transmission lines, are shown to agree very well with the experimental ones. The anomalous resonant phenomena in the transmission characteristics of a CBCPW through line and the effect of the finite-width backside plane are obtained and discussed.**

I. Introduction

WHILE increasingly gaining in popularity in MMIC designs because of the ease with which both active and passive components can be integrated on the planar surface, the coplanar waveguide (CPW) and its variants such as conductor-backed CPW (CBCPW) have been rigorously investigated. Their propagation characteristics have been studied extensively, including the potential hazards caused by leaky modes and/or overmoded problems [1]–[5]. In the real world, however, the CPW side planes and the supporting substrate can hardly extend to infinity as most of the investigators have assumed, e.g., [1], [4]. This leads to a viewpoint that one can consider the CBCPW as a system of coupled metal strips placed on a finite-width substrate surface [6] which is supported by an infinitely extended backside metal plane. The anomalous resonant effects caused by the zero cut-off microstrip-like (MSL) mode in such a finite-width CBCPW through line have been investigated in [6]. Furthermore, the backside plane of a CBCPW is often of finite extent. For an overmoded CBCPW having zero cut-off MSL mode, such a finite backside plane may exert certain influences on the CPW circuit property. To this end, this letter proposes a rigorous theoretic approach using the finite backside-plane CBCPW model described in Section II. Section III is a brief description of theories employed in the rigorous analysis of CBCPW through line. Section IV reports the results showing the noticeable effects of the finite-width backside plane on the CBCPW through-line circuit. Section V concludes the results.

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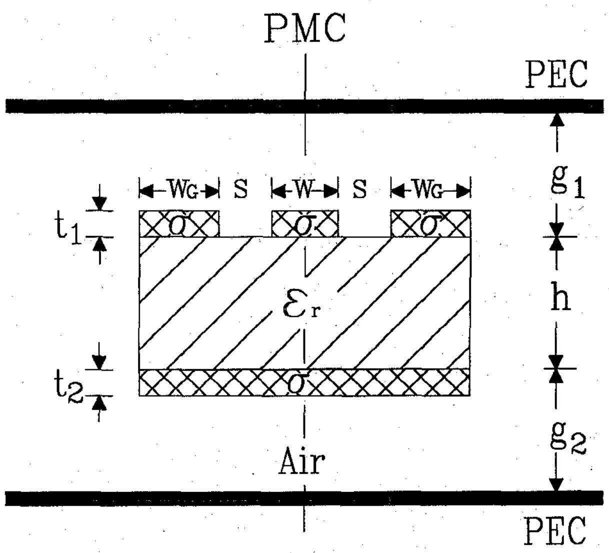

Fig. 1. The cross-sectional geometry of a symmetric finite backside-plane CBCPW. Structural dimensions are listed as follows: $W = S = 0.508$ mm, $W_G = 1$ mm, $h = 0.2$ $g_1 = 0.635$ mm, $t_1 = 20$ μm, $\sigma = 5.8 \times 10^7$ S/m, (Copper) and $\varepsilon_r = 10.2$. We assume $g_2 = t_2 = 0$ in the case of infinite backside plane and $g_2 = g_1, t_2 = t_1$ in the case of finite backside plane.

II. The Model for the CBCPW of Finite Backside Plane

Fig. 1 illustrates the model employed in our analysis. The symmetric CBCPW consists of a center signal line of width W, two side planes of width W_G, and one backside conductor plane of width $(2W_G + 2S + W)$. Two parallel perfect electric conductors (PEC's) are placed above and below the CBCPW. These two PEC's should be located far enough so that they will not perturb field distributions for both CPW and MSL modes. As a result, the model shown in Fig. 1 treats the finite backside–plane CBCPW as a four-conductor system plus the artificial grounds denoted by the PEC. By setting g_2 equal to zero, the waveguiding structure shown in Fig. 1 is reduced to a three-conductor system representing a CBCPW of infinite backside plane.

III. Method of Analysis

A. Dispersion Characteristics of the Finite Backside-Plane CBCPW

The finite backside-plane CBCPW under investigation, as shown in Fig. 1, considers the finite thickness, t_1 or t_2, and conductivity σ of the upper and backside metal strips. A rigorous full-wave mode-matching method incorporating the

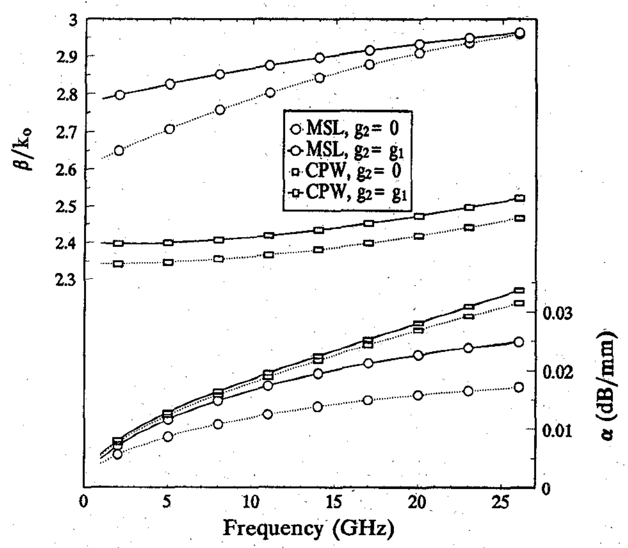

Fig. 2. The complex propagation constants on MSL and CPW modes in two cases of CBCPWs: — o — MSL mode; —□— CPW mode in the case of finite backside plane; · o · MSL mode; ·□· CPW mode in the case of infinite backside plane.

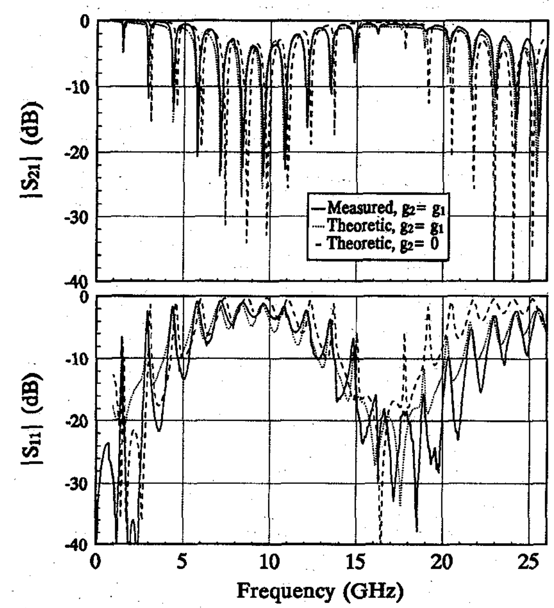

Fig. 3. Magnitude of transmission ($|S_{21}|$) and reflection ($|S_{11}|$) coefficients of two cases of CBCPW through lines. Through-line length is equal to 38.1 mm. The case of finite backside plane: ——— measured results, · · · theoretic results. The case of infinite backside plane: - - - theoretic results.

metal modes [6], [7] is utilized to calculate the complex propagation constants, modal currents and powers of the CPW and MSL modes. These results will be employed in the analysis model of CBCPW through line. Fig. 2 presents the dispersion curves of finite backside-plane CBCPW in which the structural parameters $g_2 = g_1$ and $t_2 = t_1$ are assumed. The comparative results of a infinite backside-plane CBCPW, i.e., the CBCPW model of $g_2 = t_2 = 0$ as discussed in [6], are also shown in Fig. 2 and denoted by dashed lines. Below 10 GHz, the phase constants of the MSL mode in the case of finite backside plane are significantly higher than those in the case of infinite one. The truncation of backside plane prevents some electric fringing fields of MSL mode from spreading into the air region and causes the slower phase velocity. On the other hand, the CPW mode has most of the energy confined in the slot regions. The effect of finite backside plane only contributes to the slight increase of the phase constants from 1 to 26 GHz as observed Fig. 2. If a CBCPW has the width of both the backside plane and substrate wider than $2W_G + 2S + W$, this effect of finite-width backside plane will be reduced. The image-guide-like mode [6], with most of the energy distributed over the dielectric substrate, may also propagate in this structure and cause another unexpected effect. This prevents a clear view of what effect a finite-width backside plane may have.

B. Four-Port Network Approach of CBCPW Through Line

The finite backside-plane CBCPW model described in Section II can be further simplified by placing a perfect magnetic conductor in the center of signal line. The symmetric four-conductor system is reduced to a two coupled transmission-line system which contain half a portion of signal line, a side plane, and half a backside ground plane. The MSL and CPW modes will still propagate in this half system. In accordance with experimental setting of a finite backside-plane CBCPW through line mounted on the CASCADE MTF-26 test fixture, the normalizing impedances of the two ends of signal line and side plane are 100 Ω and 0 Ω, respectively. The CBCPW through line then can be modelled by a four-port network. The two-port scattering parameters for the center signal line are derived from the four-port admittance matrix and the normalizing impedances. The four-port admittance matrix are evaluated using the $2N$-port network theory [8], [9], which incorporates the modal powers and currents of full-wave analysis. The definitions of the powerand current matrices and the formulations of the four-port admittance matrix have been reported in [6], [8], [9].

IV. Measured and Theoretic Transmission Characteristics of Finite Backside-Plane CBCPW Through Line

Fig. 3 presents the magnitude of transmission ($|S_{21}|$) and reflection ($|S_{11}|$) coefficients of the finite backside-plane CBCPW through line. The theoretic results of four-port network approach, denoted by dotted lines, are in very good agreement with the measured ones, denoted by solid lines. Many resonant points, distributed by approximately equal frequency intervals, are observed in Fig. 3. This phenomenon is attributed to the resonance of the MSL mode under the two side planes which are terminated by short circuits as the half-wavelength transmission-line resonators [6].

The theoretic results of a infinite backside-plane CBCPW through line are also superimposed on Fig. 3 by dashed lines. We have found that the effect of finite backside plane, which causes the increase of phase constant of MSL mode, makes the resonant frequencies of CBCPW through line shift downward. The maximum increase of the normalized phase constant of the MSL mode, say 5.3%, changes the first resonant frequency from 1.55 GHz to 1.48 GHz.

However, the largest frequency shift of 0.25 GHz occurs at the sixth resonant point. Furthermore, the transmission band at about 17 GHz, which is formed by the phase difference of 2π between CPW and MSL modes in CBCPW through line, is more sensitive to the discrepancy of the phase constants of MSL and CPW modes caused by the finite backside plane. The significant frequency deviation, say -0.7 GHz, in transmission band is observed when the two cases in Fig. 3 are compared.

V. Conclusion

A rigorous full-wave method and a microwave $2N$-port network approach have been applied to study the through-line propagation characteristics of the CBCPW of finite backside plane based on a proposed waveguiding model. The measured results for the transmission (S_{21}) and reflection (S_{11}) characteristics of the through line of finite backside plane agree very well with the theoretic ones. A comparison is made between CBCPW's with backside conductors of finite and infinite extents. An appreciable amount of frequency shift at each resonant frequency of the through line is observed for the two cases. The results indicate that investigators of the CBCPW circuit should consider the effect of the finite backside conductor if the overmoded situation can not be avoided.

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