Multiple Dielectric Structures to Eliminate Moding Problems in Conductor-Backed Coplanar Waveguide MIC's

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***Abstract*— Conventional conductor-backed (grounded) coplanar waveguides (CBCPW) leak energy from its dominant mode in the form of a parallel plate mode (PPM) in the substrate region at all frequencies which can generate undesirable coupling effects and produce an ineffective circuit. A multiple dielectric structure with appropriate dimensions is used to suppress the leakage effects and the spectral domain method (SDM) predicts the critical frequency (transition point for leaky and nonleaky modes) for the waveguide. Experimental data verifies this procedure and demonstrates the significance of the moding (leakage coupling) problems.**

I. Introduction

COPLANAR waveguides, with conductor backing to support the structure (see Fig. 1), offer an attractive alternative to microstrip as a transmission media for microwave integrated circuits (MIC's) [1]. The usefulness of CBCPW was questioned after measurements of a through line repeatedly produced undesirable results similar to Cases A and B in Fig. 2. This problem is attributed to a zero cutoff frequency TEM PPM with a zero critical frequency that occurs in CBCPW for any dielectric constant and thickness [2]. Besides causing a loss of energy from the dominant CBCPW mode, the leaked energy can couple to other parts of the circuit producing unexpected effects [2] as in Fig. 2. According to [3], leakage in CBCPW MMIC's can be reduced by decreasing the cross section (W+2S) or increasing the substrate thickness, and with these modifications estimates any coupling effects with the TEM PPM should be small. However, in MIC's, the available line dimensions are restricted and increasing the thickness may excite additional PPM's that enhance the leakage problems. The leaked energy propagates in the dielectric and reflects within the structure formed by the top and bottom ground planes and the front, back, and side terminations of the CBCPW forming a standing wave. Depending on the frequency this standing wave can strongly affect the dominant CBCPW mode [2]. This explanation of the resonance phenomenon for Cases A and B of Fig. 2 is justified because no higher order PPM's contributing to the leakage are present. All of the line parameters were varied to eliminate these coupling effects, but these changes still did not produce a waveguide with any appreciable bandwidth. Such attempts include Case C (modified CBCPW [4]) of Fig. 2 and a structure with a small cross section compared to the dielectric thickness ($\epsilon_{r2} = 10.2$, $\epsilon_{r1} = 1$, $h2 = 2.54$ mm, $h1 = 0, W + 2S = 1.02$ mm). Efforts to suppress the leakage coupling problems in CBCPW have included the placing of via-holes between the top and bottom ground planes [5] and the use of absorbing material [6], but these methods are not advantageous for integrated circuits.

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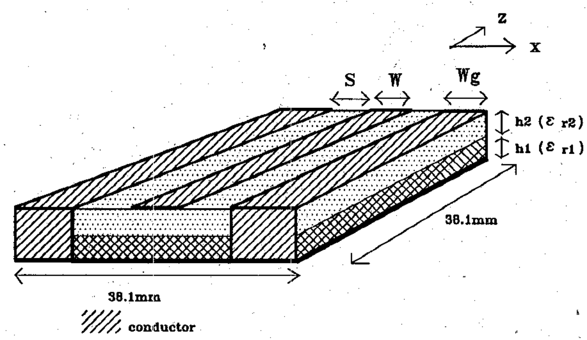

Fig. 1. Symmetrical multiple dielectric CBCPW structure. W, S, Wg are respective widths of the center conductor, the slots, and the top side ground conductors. *h* is the thickness of each substrate. All dimensions in the text are referenced to this figure.

The most practical structure based on our experimental data for wide-band use incorporates a multiple dielectric configuration as suggested in [1] (e.g., $\epsilon_{r2} = 10.2$, $\epsilon_{r1} = 2.2$) to lower the propagation constant of the PPM's below the dominant CBCPW mode and prevent any leakage from occurring. This lower substrate also supports the top substrate containing the active components. The SDM generates a dispersion curve for the above waveguide to establish the critical frequency for the leaky modes. This procedure is verified with experimental data and demonstrates how to design CBCPW for broad-band MIC applications.

II. Analysis

The SDM is used to determine the frequency dependent propagation characteristics of CBCPW with the top side ground planes extending to the edge of the substrate (x direction of Fig. 1). The analysis follows from [7] and [8] and assumes a lossless and infinitely wide and long structure. The longitudinal and transverse electric fields across the slots are expanded using sinusoidal functions corrected by the edge condition

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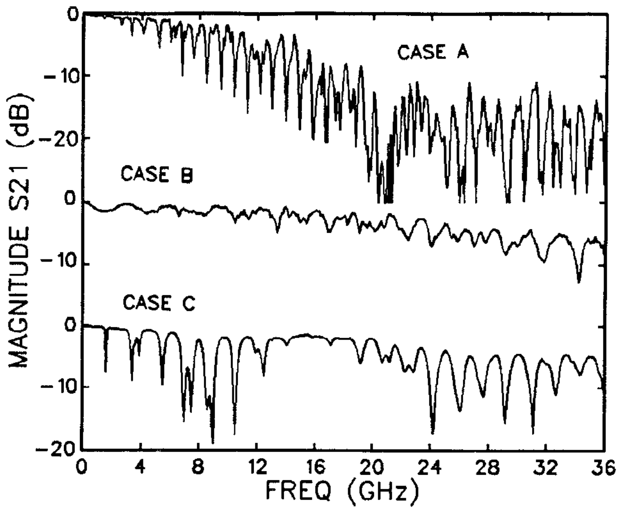

Fig. 2. Experimental data of the leakage coupling problems in CBCPW MIC's. Case A ($\epsilon_{r2} = 10.2$, $\epsilon_{r1} = 1$, $h2 = 0.635$ mm, $h1 = 0$. $W = S = 0.508$ mm, $Wg = 18\ 29$ mm), Case B (same as Case A except $\epsilon_{r2} = 2.2$), Case C (same as Case A except $Wg = 1$ mm) are marked.

term [8]. The poles of the Green's function correspond to the characteristic PPM's [7] with a propagation constant k_p and are calculated using a bisection approach and Muller's method [9]. The propagation constant of the dominant CBCPW mode (symmetrical structure with a vertical magnetic wall at the center of the inner strip (W) of Fig. 1) [8] is β. For frequencies where k_p is greater than β, the dominant CBCPW mode becomes leaky and is no longer purely bound and the leaked energy travels at an angle to the direction of propagation (z axis of Fig. 1) within the dielectric [2]. The critical frequency occurs when $k_p = \beta$ and below this frequency no leakage results. SDM can calculate the leakage loss of the CBCPW mode [7], [10] but does not predict the resonance effects observed in our experimental data because the method assumes an infinitely wide and long structure. In a finite waveguide, the leaked energy experiences reflections and couples to the dominant CBCPW mode and requires a three-dimensional analysis to estimate the data of Fig. 2.

Fig. 3 displays a dispersion curve where k_p refers to the TM_0 PPM (lowest order PPM supported by the structure). The two-dielectric CBCPW configuration behaves as an inhomogeneous parallel plate waveguide and the TEM PPM of the conventional CBCPW is no longer present. Case 1 shows that a lower dielectric constant is required for the bottom substrate ($\epsilon_{r1}, h1 = \infty$ (infinitely thick)) since $k_p > \beta$ across the frequency range. Case 2 predicts a broad-band transmission line since $k_p < \beta$, while Case 3 demonstrates a critical frequency at 21 GHz. For Case 3, no higher order PPM's contributing to the leakage are present. From our experimental data, the critical frequency defines the approximate upper frequency for usable operation of the CBCPW. A total of five basis functions were included for the previous simulations and each frequency point required approximately 45 seconds on a 386 PC with math coprocessor.

III. Results

The results described here are based on S-parameter data

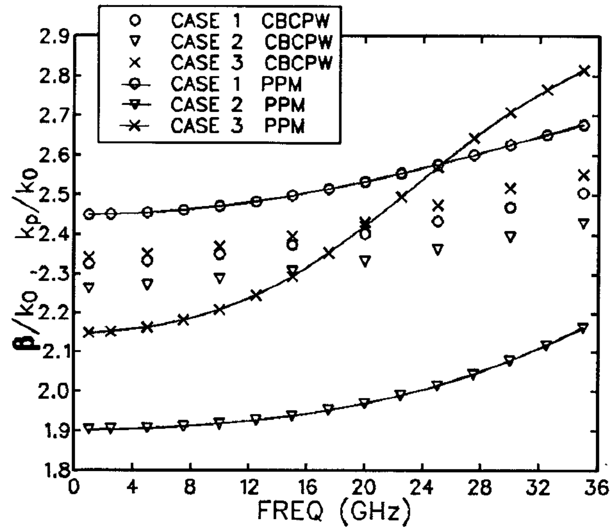

Fig 3. Dispersion curve produced by SDM. The normalized propagation constants of CBCPW and TM_0 PPM modes are indicated. Case 1 ($\epsilon_{r2} = 10.2$, $\epsilon_{r1} = 6$, $h2 = 0.635$ mm, $h1 = \infty$, $W = 2S = 0.635$ mm, $Wg = 18.42$ mm). Case 2 (same as Case 1 except $\epsilon_{r1} = 2.2$, $h1 = 0\ 635$ mm), Case 3 (same as Case 2 except $h2 = 1.27$ mm) are marked.

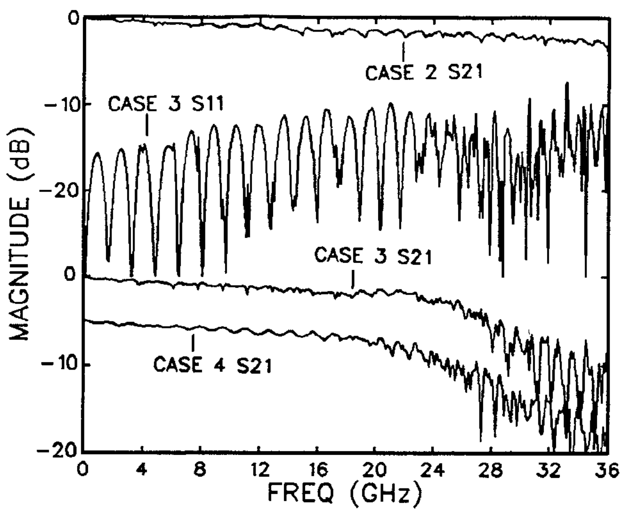

Fig. 4. Experimental verification of results from Fig. 3. Case 4 (same as Case 3 except $h1 = 0.381$ mm) is referenced 5 dB down from Case 3 S21. Case 3 S11 corresponds to the top scale.

of CBCPW through lines collected on a test fixture up to a frequency of 36 GHz with an HP8510B network analyzer using Rogers Duroid™ substrates. The bottom conductor is connected to the top ground plane (see Fig. 1) by copper tape that folds around the front and back sides of the board. We verified that the resonance problems in the data were not due to the excitation of the slotline mode [3] (copper tape air bridges across the top side ground planes were included) or radiation effects above the transmission line (cover housing with a groove along the length and wider than the CBCPW cross section had a minimal affect on the response).

Fig. 4 displays experimental data corresponding to the cases described in Fig. 3. Case 2 displays a wide-band response as predicted. The line loss in this case is approximately equivalent to that measured of a 50-ohm microstrip test line

($\epsilon_r = 10.2$, $h = 0.635$ mm). Case 3 shows problems in the S21 curve above approximately 23 GHz and is verified in the S11 data. The slight discrepancy between the computed critical frequency and the measured frequency where the moding problems begins is due to the infinite width and length assumption of the CBCPW in the analysis. The SDM for Case 4 calculates a lower critical frequency than for Case 3, as would be expected since h1 is smaller in Case 4 and this difference is also confirmed in Fig. 4. The small spikes in the S21 curve for Case 3 below the critical frequency may be attributed to small air gaps between the substrates or the excitation of an extraneous mode at the connector launch point due to a potential difference between the top and bottom ground planes [11].

IV. Conclusion

It is desirable to use CBCPW in broad-band MIC applications, however, we have shown the interference and crosstalk caused by the leaked energy from the CBCPW mode may prevent this. A multiple dielectric configuration is utilized (as suggested in [1]) to eliminate the leakage effects and a simple procedure is employed to verify the waveguide parameters to achieve useful wide-band results. Future work will include a precise explanation and prediction of the resonance mechanism observed in our data above the critical frequency and propose further modifications in CBCPW to minimize these effects.

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