MULTILAYER APERTURE-COUPLED BROADSIDE MICROSTRIP LINES

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ABSTRACT

This paper describes new multilayer aperture-coupled broadside microstrip lines suitable for miniaturized microwave monolithic integrated circuits (MMICs). The new transmission line structure is applicable to both loose and tight coupling applications. The quasi-static spectral domain method is used to determine both the *c*- and π-mode characteristic impedances and effective dielectric constants.

I. INTRODUCTION

In the past decade we have witnessed a rapid advancement of microwave monolithic integrated circuits (MMICs) for both civilian and military applications. Recently, efforts have also been focused on reducing the sizes of current MMICs through the use of thin-film microstrip lines fabricated on thin dielectric substrates over a GaAs semi-insulating substrate [1]. The thin-film microstrip lines have narrow line widths due to the use of very thin dielectric layers, and thus make high-density circuit integration feasible. However, these thin-film microstrip lines are single transmission lines, and therefore are not applicable for MMICs using parallel-coupled lines such as filters and couplers.

This paper proposes a new multilayer parallel-coupled microstrip structure (Fig. 1) suitable for miniaturized MMICs. It consists of two dielectric layers (e.g., silicon oxynitride), isolated by a common ground plane, over a grounded dielectric substrate (e.g., GaAs). The strips are located on two different layers and coupled to each other through a rectangular aperture on the common ground plane. Both weak and strong couplings can be achieved by adjusting the size of the coupling aperture. Through the use of thin dielectric layers, narrow line-widths can also be obtained, resulting in compact circuits. Furthermore, due to the use of a common ground plane, unwanted couplings between circuits on the two layers are eliminated. In addition, the proposed structure can have significantly less distortion via appropriate selection of dielectric layers. A similar structure, consisting of two dielectric substrates and two microstrip lines coupled through a rectangular slot in a common plane, was analyzed [2,3]. However, the reported structure is not suitable for MMICs and, to some extent, MICs, since the substrates are assumed to be suspended in the air. In addition, it is not flexible and does not have the ability to optimize the transmission line's characteristics. An analysis for the new structure, using the quasi-static spectral domain method (SDA) [4], is presented. Both mode characteristic impedances and effective dielectric constants are obtained.

II. FORMULATION

Fig. 1 shows a cross section of the proposed multilayer aperture-coupled microstrip lines. The conductors are assumed to be perfectly conducting and infinitesimally thin, and the dielectric substrates are assumed to be lossless. The structure supports two quasi-TEM propagation modes, designated as *c*- and π-modes. By using the quasi-static SDA, which utilizes Galerkin's method, described in [4], one can derive the following set of coupled linear algebraic equations.

$$\sum_{m=1}^{M} P_{11}^{im} c_m + \sum_{k=1}^{K} P_{12}^{ik} d_k + \sum_{n=1}^{N} P_{13}^{in} f_n = Q_i,$$

$$\sum_{m=1}^{M} P_{21}^{jm} c_m + \sum_{k=1}^{K} P_{22}^{jk} d_k + \sum_{n=1}^{N} P_{23}^{jn} f_n = 0,$$

$$\sum_{m=1}^{M} P_{31}^{lm} c_m + \sum_{k=1}^{K} P_{32}^{lk} d_k + \sum_{n=1}^{N} P_{33}^{ln} f_n = 0.$$

$$P_{11}^{im} = \int_{-\infty}^{\infty} \tilde{\rho}_{si} \tilde{G}_{11} \tilde{\rho}_{sm} d\beta$$

$$P_{12}^{ik} = \int_{-\infty}^{\infty} \tilde{\rho}_{si} \tilde{G}_{12} \tilde{\rho}_{gk} d\beta$$

$$P_{13}^{in} = \int_{-\infty}^{\infty} \tilde{\rho}_{si} \tilde{G}_{13} \tilde{\rho}_{sn} d\beta$$

$$P_{21}^{jm} = \int_{-\infty}^{\infty} \tilde{\rho}_{gj} \tilde{G}_{21} \tilde{\rho}_{sm} d\beta$$

$$P_{22}^{jk} = \int_{-\infty}^{\infty} \tilde{\rho}_{gj} \tilde{G}_{22} \tilde{\rho}_{gk} d\beta$$

$$P_{23}^{jn} = \int_{-\infty}^{\infty} \tilde{\rho}_{gj} \tilde{G}_{23} \tilde{\rho}_{sn} d\beta$$

$$P_{31}^{lm} = \int_{-\infty}^{\infty} \tilde{\rho}_{sl} \tilde{G}_{31} \tilde{\rho}_{sm} d\beta$$

$$P_{32}^{lk} = \int_{-\infty}^{\infty} \tilde{\rho}_{sl} \tilde{G}_{32} \tilde{\rho}_{gk} d\beta$$

$$P_{33}^{ln} = \int_{-\infty}^{\infty} \tilde{\rho}_{sl} \tilde{G}_{33} \tilde{\rho}_{sn} d\beta$$

where $\tilde{G}$'s represent the spectral domain Green's functions, β is the Fourier transform variable and $\varepsilon_{r1,2,3}$ are the relative dielectric constants of the substrates. c_m , d_k and f_n are the unknown coefficients, associated with the known basis functions ρ_s and ρ_g that describe the charge distributions on the strips and the common ground plane, respectively. The tilde (~) indicates the Fourier-transformed quantity.

The constants c_m , d_k and f_n can now be solved from the above equations, from which the charge distributions on the strips can be obtained. Next, the *c*- and π-mode per-unit-length capacitances of the strips are determined. Finally, the *c*- and π-mode characteristic impedances and effective dielectric constants can be found from the *c*- and π-mode capacitances.

III. NUMERICAL RESULTS

Using the charge distributions, which employ polynomials as basis functions, various numerical results for the *c*- and π-mode characteristic impedances and effective dielectric constants have been computed. Fig. 2 shows typical plots of the mode impedances and effective dielectric constants versus the strip width for a structure consisting of two silicon oxynitride layers ($\varepsilon_{r1} = \varepsilon_{r2} = 5$; $h_1 = h_2 = 5\mu$m) over a thick GaAs substrate ($\varepsilon_{r3} = 12.9$; $h_3 = 25$ mil). This particular structure represents an example for possible GaAs MMIC processing.

IV. CONCLUSIONS

Newly developed multilayer aperture-coupled microstrip lines have been presented along with an analysis based on the quasi-static

SDA. This structure is applicable for microwave integrated circuits with both weak and strong coupling requirements. The new structure is especially attractive for developing compact MMICs by using very thin dielectric layers over a GaAs substrate.

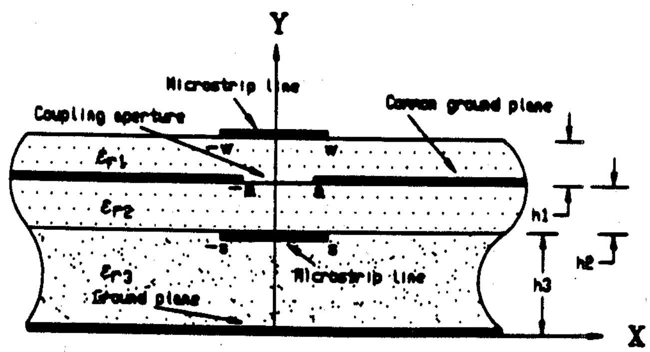

Fig. 1 Multilayer aperture-coupled broadside microstrip lines.

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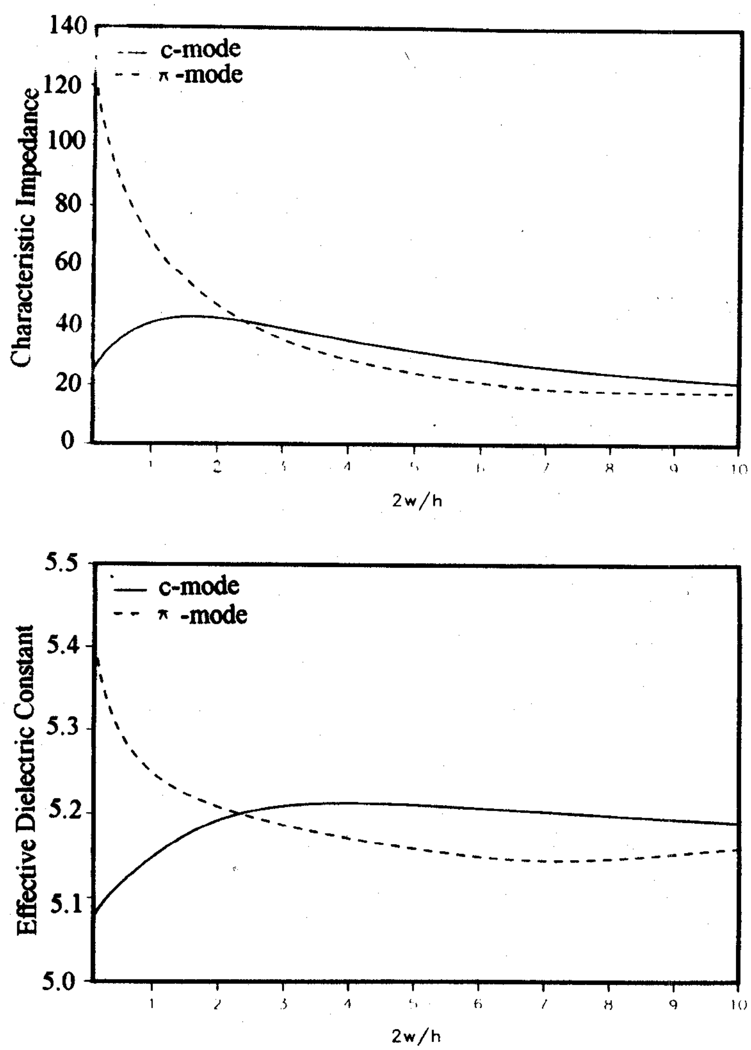

Fig. 2 Mode characteristic impedances (a) and effective dielectric constants (b) for a structure with $h_1 = h_2 = 5$ μm, $h_3 = 25$ mil, $2s = 16$ mil, $2a = 8$ mil, $\varepsilon_{r1} = \varepsilon_{r2} = 5$, $\varepsilon_{r3} = 12.9$.