MULTILAYER PLANAR STRUCTURES FOR HIGH DIRECTIVITY DIRECTIONAL COUPLER DESIGN

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ABSTRACT

One of the problems that appear in the directional couplers designed with coupled transmission lines embedded in nonhomogeneous medium is their poor directivity. In this work several multilayer configurations for high directivity coupler design are studied by means of a variational technique in the spectral domain, and a set of curves for an optimum design are included

INTRODUCTION

The growing complexity of microwave integrated circuitry, and the quality requirements of basic components, are making VSWR and isolation of directional couplers increase.

As it is well known, a coupled transmission line (CTL) coupler with unequal even- and odd-mode lengths suffers from low directivity. Due to this reason, microstrip directional couplers made of parallel CTL exhibit a reduced directivity. Several methods for compensation have been proposed. In this way, overlay techniques are reported, for example, by Haupt and Delfs (1), Paolino (2) and Alexopoulos et al. (3). Shibata et al. (4) show that adjustment of airgap in suspended microstrip lines allows to compensate the difference of the even- and odd- mode phase velocities. The aniso - tropy of the dielectric substrate has been also considered in order to improve the directivity of couplers (5-7).

In this work we analyze a variety of multi-layer configurations with iso/anisotropic dielec - trics, which permit us to get equal mode phase velocities for edge- and broadside- coupled strips. The analysis is achieved by using the variational technique ib the spectral domain reported in (8). For each of these structures a couple of graphics for optimum design are shown.

ANALYSIS

The coupled structures to be analyzed are shown in fig. 1. Figs. 1.a and 1.b represent edge-coupled microstrip configurations suitable for weak coupling, and figs. 1.c and 1.d represent broadside- coupled strips, which provide strong coupling between the conductors. All these struc - tures are particular cases of the generic multi - layered planar transmission line analyzed by the authors in (8) assuming lateral side walls apart enough.

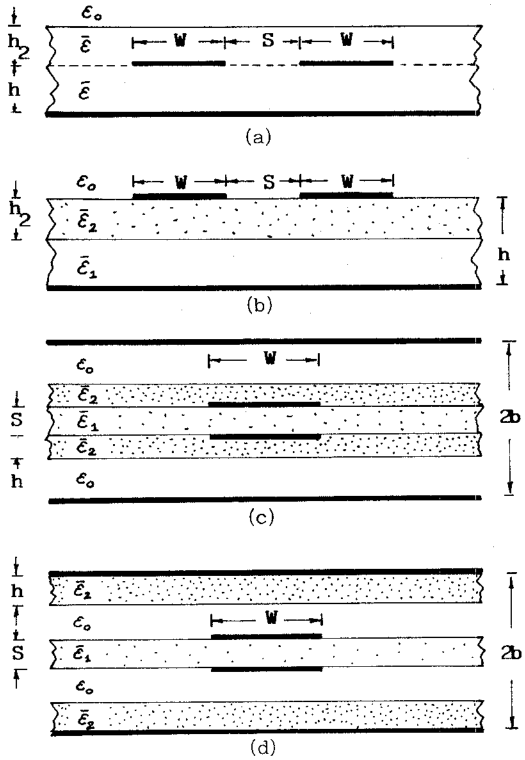


Fig. 1.- Cross sections of the coupled strip structures analyzed in this work

In this work we will assume perfect conductor strips with valueless thickness. Besides, we will consider the quasi-TEM assumption to be valid. In this way, mode capacitances can be written in the spectral domain as follows:

$$C_{e,o} = (1/LV^2) \sum_{n=1}^{\infty} \tilde{L}(n) \, |\tilde{V}(n)|^2 \qquad (1)$$

$$(1/C_{e,o}) = (1/LQ^2) \sum_{n=1}^{\infty} \tilde{G}(n) \, |\tilde{\rho}(n)|^2 \qquad (2)$$

where $\tilde{V}(n)$ and $\tilde{\rho}(n)$ are respectively the Fourier transforms of the potential function, and the surface charge density at the interface where the strips are located; $\tilde{G}(n) = (\tilde{L}(n))^{-1}$ is the spectral Green's function of the structure, and Q and V are the charge and the potential of the strips for each mode.

The expressions (1) and (2) are useful to calculate upper and lower bounds on mode capacitances respectively. If we use adequate trial functions to approximate the unknown surface charge density or the potential function and we apply the Rayleigh-Ritz's minimization procedure, very accurate results are obtained. The method above sketched and the trial functions used can be seen in (8).

RESULTS

The method described has been used to write a computer program to analyze the configurations in fig. 1. Upper and lower bounds on mode capacitances were generated to check the results. Agreement better than 0.2 % of the average value was found for practical dimensions.

As it can be seen in fig. 1, these structures are obtained by modifying the simpler edge- coupled or broadside - coupled strip configurations. The addition of one dielectric layer permits us to match the even and odd mode phase velocities by changing its thickness. In the following paragraphs we will present a condensed study of these CTL configurations.

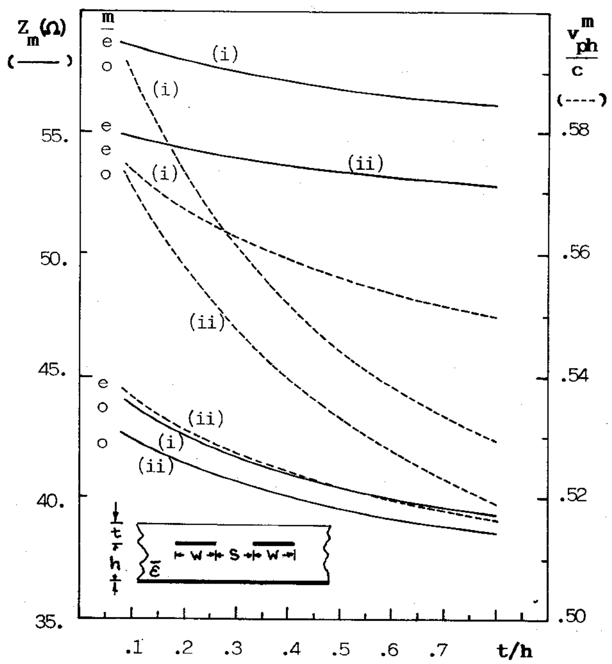


Fig. 2.- Edge- coupled strips embedded in

(i) P.B.N. ($\varepsilon^*_x = 5.12$, $\varepsilon^*_y = 3.40$)

(ii) an isotropic dielectric with $\varepsilon^*_r = 4.10$ ($\approx\sqrt{\varepsilon^*_x \cdot \varepsilon^*_y}$)

Varying the ratio t/h, mode phase velocities can be matched in case (i), but this is not possible in case (ii).

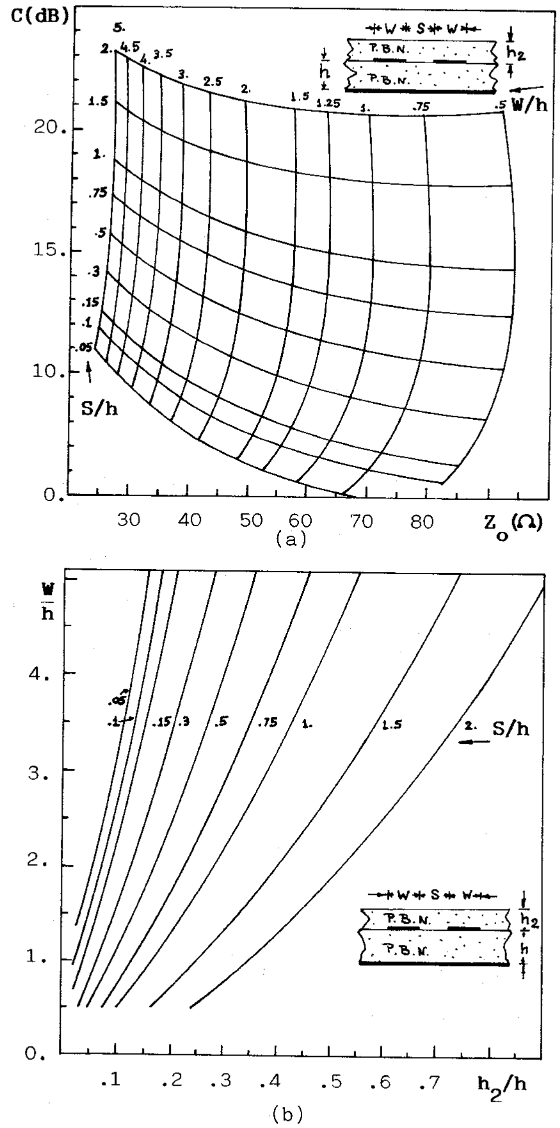


Fig. 3.- Design curves for edge - coupled strips embedded in P.B.N.

a) Coupling at the central frequency (CF) versus characteristic impedance.

b) Optimum h_2/h ratio.

a) Edge- coupled lines with overlay (fig. 1. a)

Overlay configurations have been studied in (1-3) . The structure proposed here differs from those ones because of the use of an anisotropic substrate and superstrate made of the same material. As it can be seen in fig.2, by varying the thickness of the overlay, it is possible to match the mode phase velocities if P.B.N. is used as a low loss dielectric (ε^*_x=5.12; ε^*_y=3.40). Also it is apparent from this figure that if an equivalent isotropic dielectric is used ($\varepsilon^*_{x,y}$= 4.10), matching cannot be achieved with a finite thickness overlay (from a theoretical point of view). For each pair of values (W,S) we find an optimum overlay thickness (h_2)

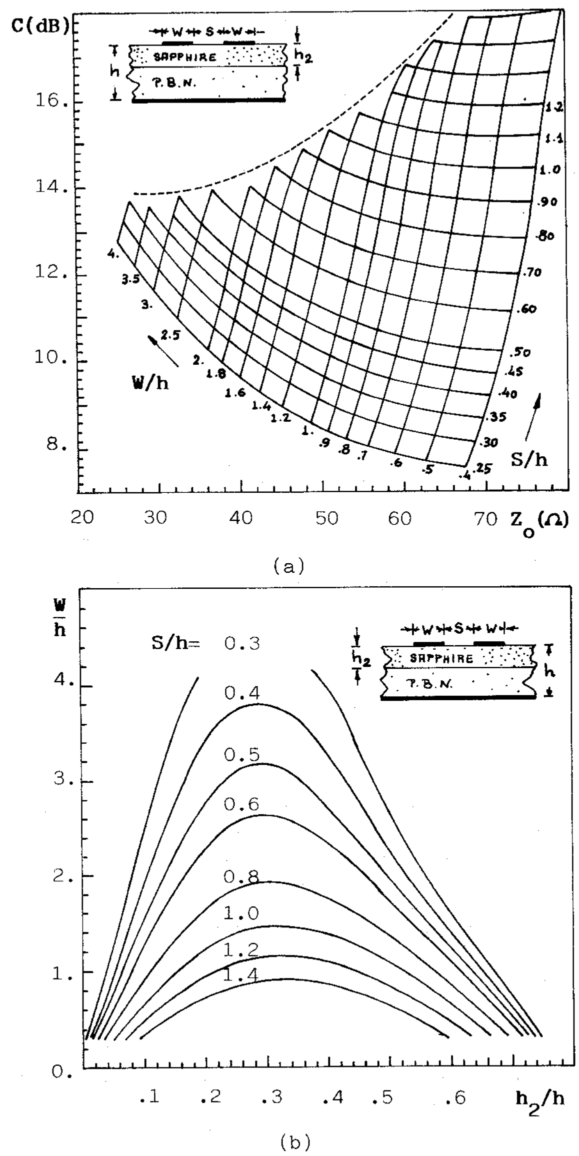


Fig. 4.- Design curves for edge- coupled strips on a double - layer substrate P.B.N.-sapphire
a) Coupling at the CF versus characteristic impedance.
b) Optimum h_2/h ratio.

which yields equal mode phase velocities. In this way, we have written a computer program to obtain the optimum shape ratios in the sense previously stated. The results are shown in a graphic form in fig. 3 . Once we have fixed the coupling at the central frequency (C(dB)) and the characteristic impedance (Z_o) of the coupler, we can obtain the values of W and S from fig. 3.a. Using these values in fig. 3.b we obtain the optimum overlay thickness.

b) Edge- coupled lines on two substrates. (fig. 1.b)

As it was stated in (9), we also can match the mode phase velocities by using two layers of different materials as a compound substrate. For each pair (W,S), there are two values of the ratio h_2/h which permit us to equalize the even and odd mode phase velocities. Obviously , the coupling factor is the same for both matching points, but, the characteristic impedance is different. In this way, proceeding like in paragraph (a), two different graphics C(dB) versus Z_o can be drawn. However, we only present here (see fig. 4.a) the graphic corresponding to the higher value of h_2/h, because by using these dielectric materials (sapphire and boron nitride) this value yields adequate impedance levels. Once we decided the required values of Z_o and C(dB), we use this graphic to determine the pair (W,S) and next, the optimum value of h_2/h is

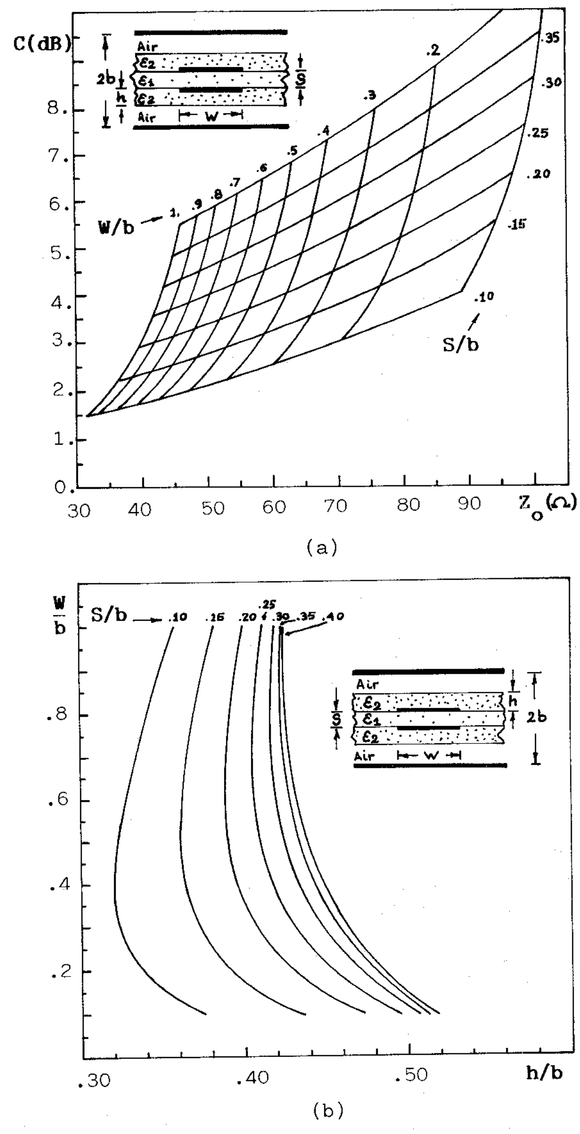
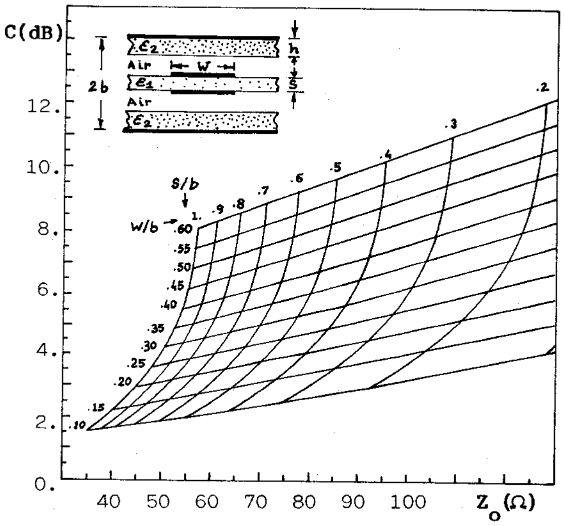
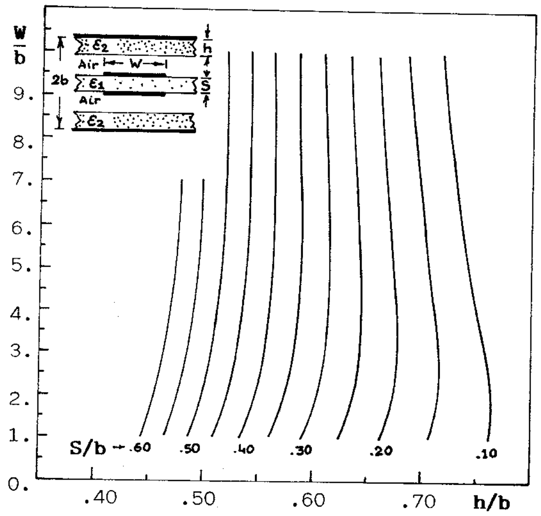


Fig. 5.- Design curves for broadside - coupled strips with overlay ($\varepsilon_1^* = 2.50$; $\varepsilon_2^* = 10.00$)
a) Coupling at the CF versus characteristic impedance.
b) Optimum h/b ratio.



(a)



(b)

Fig. 6.- Design curves for broadside- coupled strips with two layers ($\varepsilon_1^* = 2.50$; $\varepsilon_2^* = 10.00$)

a) Coupling at the CF versus characteristic impedance.
b) Optimum h/b ratio.

obtained from fig. 4.b (there are two possible values of h_2/h but, in this case, we must choose the higher one).

This configuration can be useful to avoid the air bubbles problem that present the overlay configuration.

c) Broadside-coupled strips with overlay. (fig. 1.c)

This configuration is similar to the one studied in paragraph (a), but it allows us to get very stron coupling with practical dimensions. Broadside- coupled strips without superstrate yield large phase velocity ratios, but if we use a high permittivity overlay, mode phase velocities will be matched (10). A pair of curves similar to the above reported is also supplied in figs. 5.a and 5.b.

d) Broadside-coupled strips with two layers.(fig.1.d)

This an alternative configuration to the one described in (c). In this structure there is an air gap between the dielectric layers, and air bubbles between them is no longer a problem. In (10) is proved that by varying the thickness of the high permittivity substrate, mode phase velocities can be equalized. In figs. 6.a and 6.b, the co - rresponding design curves are represented.

CONCLUSIONS

The variational approach in the spectral domain is a powerful tool to analyze the propagation parameters in quasi - TEM mode of multilayered configurations. This method has been used to study several simple coupled configurations. These structures can be useful in the design of high directivity directional couplers. A set of computer programs has been written to provide optimum design curves for each of the structures presented in the work.

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