ANALYSIS AND DESIGN OF SLOT-COUPLED DIRECTIONAL COUPLERS BETWEEN DOUBLE-SIDED SUBSTRATE MICROSTRIP LINES

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ABSTRACT

This paper proposes to study the characteristics of a slot-coupled directional coupler between two microstrip lines coupled through a rectangular slot in the common ground plane. Firstly, conformal mapping techniques are used to obtain analytic closed-form expressions for the coupler even and odd-mode impedances and propagation constants for any coupler configuration. Secondly, a full-wave analysis is performed using the spectral domain approach to determine the dispersion properties of coupler parameters. Theoretical and experimental results for a 10 dB coupler at 10 GHz are presented.

I - INTRODUCTION

A new slot-coupled directional coupler between two microstrip lines coupled through a rectangular slot in the common ground plane (Fig.1) was proposed for the first time by Tanaka et al. [1]. This coupler can find important applications in the design of beam forming networks and multiport amplifiers through the use of this new coupler in the construction of planar multiport directional couplers without the necessity of using microstrip cross-overs. This coupler enables both tight and loose coupling values to be achieved. Here, firstly we propose to use conformal mapping techniques to obtain analytic closed-form expressions for its quasi-static even and odd-mode parameters. Results using these expressions are in a very good agreement with those obtained by Tanaka et al. using a heavy numerical method (finite element method) always for the quasi-static case. Secondly, a full wave analysis using spectral domain approach is performed to obtain the dispersion characteristics of the coupler even and odd-mode parameters.

II - QUASI-STATIC ANALYSIS

Conformal transformations techniques are used to calculate the coupler even and odd-mode capacitances per unit lenght. This analysis leads to analytic closed form expressions for coupler even and odd-mode impedances and propagation constants for any line configuration and substrate thickness. Fig.2 shows a comparison between our results using conformal transformations and those of Tanaka et al. [1]. A good agreement is noticed with a deviation which does not exceed 5 percent for the even-mode characteristics and 1 percent for the odd-mode ones.

III - FULL WAVE ANALYSIS

It is clear that the existence of the slot in the common ground plane does not affect the coupler odd-mode characteristics which are similar to those for a microstrip line. While for the even-mode, the coupling slot plane is a magnetic wall. So, using the conventional spectral domain approach [2], the tangential electric field on the slot plane and the current on the strip plane are related to the current on the slot plane and the tangential electric field on the strip plane through the Fourier tranformed Green's function matrix as is given in (1).

$$\begin{pmatrix} J_x(\alpha_n,-h/2) \\ J_z(\alpha_n,-h/2) \\ E_x(\alpha_n,h/2) \\ E_z(\alpha_n,h/2) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \\ h_{41} & h_{42} & h_{43} & h_{44} \end{pmatrix} \cdot \begin{pmatrix} E_x(\alpha_n,-h/2) \\ E_z(\alpha_n,-h/2) \\ J_x(\alpha_n,h/2) \\ J_z(\alpha_n,h/2) \end{pmatrix} \quad (1)$$

with $\alpha_n = (2n-1)\pi/b$

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The matrix [h] can be derived by solving the Maxwell equations with the boundary conditions in the Fourier domain [2]. The Galerkin procedure is applied to solve (1). The tangential electric field and the current in the right column are expanded in terms of a set of suitable basis functions. The dispersion equation is obtained using Parseval's theorem.

The characteristic impedance is calculated according to power-current definition $Z_c = 2P/I^2$.

IV - COUPLER DESIGN

The common formulas for designing quarter wavelength coupler using symmetric lines are usued:

$$C_{ab} = -20\log[(Z_{ce} - Z_{co})/(Z_{ce} + Z_{co})] \qquad Z_o = \sqrt{Z_{ce} Z_{co}} \qquad (2)$$

The modal impedances Z_{ce}, Z_{co} and modal phase constants β_e, β_o of the fundamental mode are determined by the spectral domain analysis. The basis functions corresponding to the even fundamental mode are:

$$e_x(x,-h/2) = 2x/G[1-(2x/G)^2]^{-1/2} \quad ,|x| \le G/2, \qquad (3)$$
$$0 \quad \text{elsewhere}$$

$$e_z(x,-h/2) = \sqrt{1-(2x/G)^2} \quad ,|x| \le G/2,$$
$$0 \quad \text{elsewhere}$$

$$j_x(x,h/2) = 2x/W\sqrt{1-(2x/W)^2} \quad ,|x| \le W/2,$$
$$0 \quad \text{elsewhere}$$

$$j_z(x,h/2) = 1/\sqrt{1-(2x/W)^2} \quad ,|x| \le W/2,$$
$$0 \quad \text{elsewhere}$$

Figures 3,4 and 5 show examples of design curves that give respectively the normalized wavelength, the characteristic impedance and the coupling coefficient vs. the normalized strip-width W for different G/W ratios at a frequency of 10 GHz.

V - EXPERIMENTAL RESULTS

A 10db coupler is realized having the followingg parameters

$Z_{ce} = 69.4\ \Omega$ $Z_{co} = 36\ \Omega$ $Z_o = 50\ \Omega$

$\epsilon_r = 10.5$ $W = 1.087$ mm $G = 2.120$ mm $L = 2.818$ mm

The coupling and the isolation are presented in fig. 6 and 7. Good agreement is obtained between theoretical and experimental curves. The coupler bandwidth is about 10% around 10.25 Ghz, the coupling is 10.2 ± 0.2 db.

VI - REFERENCES

[1] T. Tanaka, K. Tsunoda and M. Aikawa, "Slot-coupled directional couplers on a both-sided substrate MIC and their applications", Electonics and communications in Japan, Part 2, Vol. 72, No. 3, 1989.

[2] M. Helard, J. Citerne, O. Picon, V. Fouad Hanna, "Theoretical and experimental investigation of finline discontinuities", IEEE Trans. on MTT, oct. 1985.

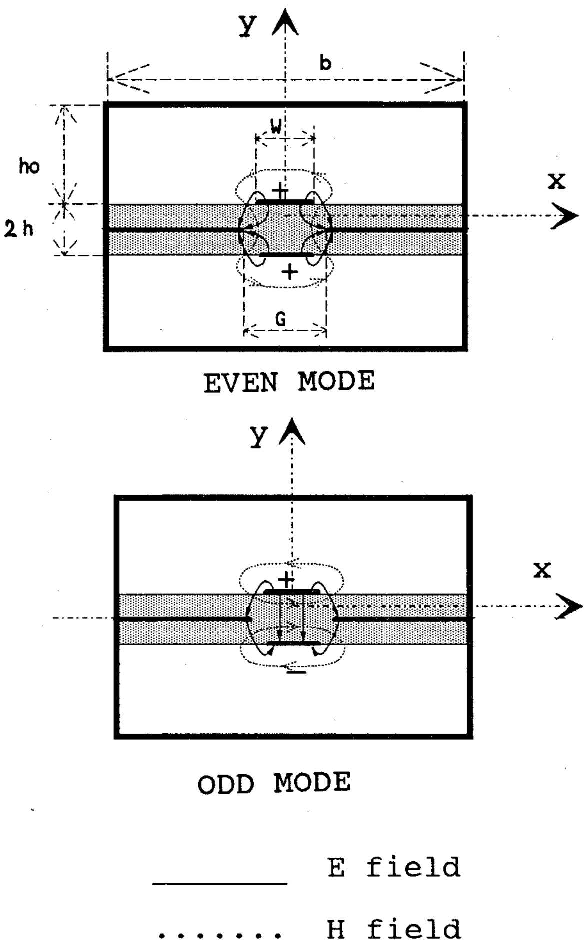


figure 1

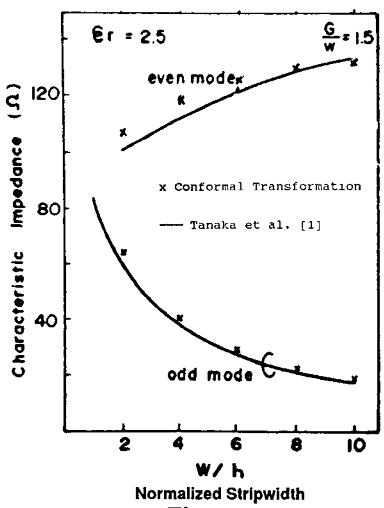
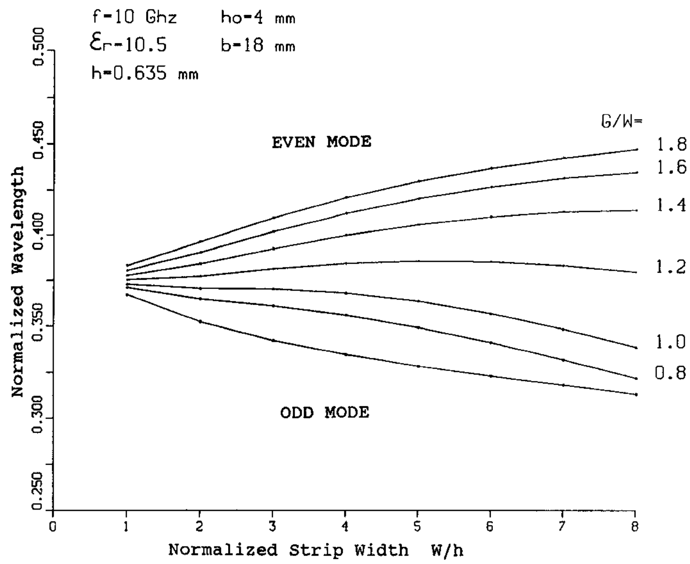


Figure 2.



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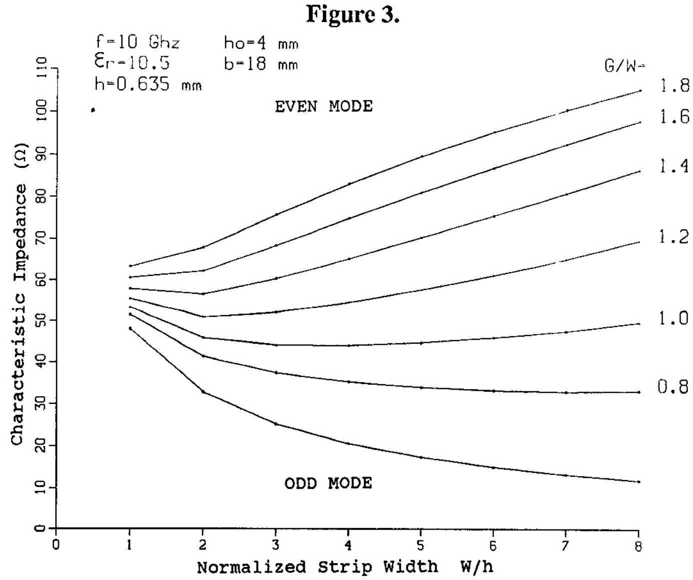

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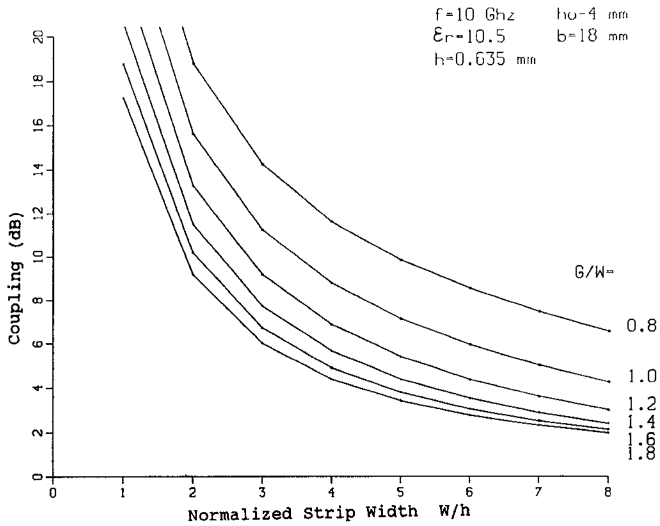

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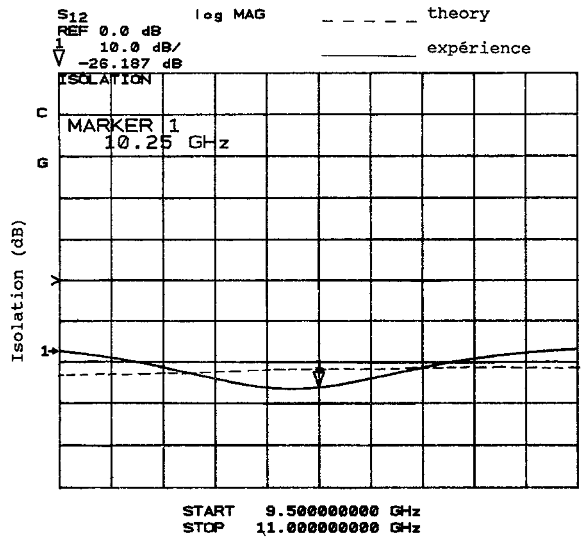

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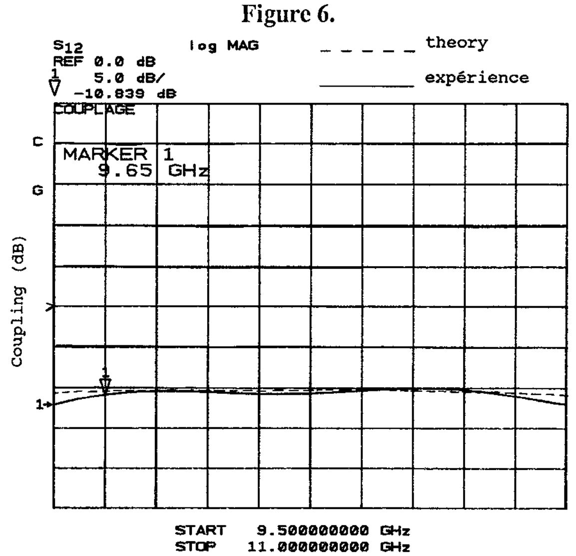

Figure 7.