SIMPLE CAD FORMULAS OF EDGE-COMPENSATED MICROSTRIP LINES

Eikichi Yamashita, Hideyuki Ohashi, and Kazuhiko Atsuki

University of Electro-communications
Chofu-shi, Tokyo, Japan 182

ABSTRACT

The proximity effects of microstrip lines near a substrate edge are estimated by using the rectangular boundary division method for effectively designing high-packing-density MMIC's. Simple CAD formulas of edge-compensated microstrip lines (ECM lines) are introduced which can be applied to circumvent the proximity effects on the characteristic impedance.

I. INTRODUCTION

Pucel has pointed out the significance of "proximity effects" of two types which appear when designing circuit patterns of high-packing-density GaAs MMIC's, and calls attention to the absence of analysis methods to estimate the effects theoretically [1][2].

One type of proximity effects is observed when a strip conductor is near a conductor having ground potential on the top surface of the substrate. This type has already been analyzed by one of the authors in a recent paper [3]. The second type is observed when a strip conductor is located close to a substrate edge. Estimation methods or exact CAD methods for these proximity effects are urgently required to avoid tweaking after fabrication processes. The characteristics of the finite-width open microstrip line have been studied based on a free space Green's function approach in the past [4].

In this paper, the proximity effects of the second type are analyzed by using the rectangular boundary division method proposed in a previous paper [5]. It is assumed that the cross-sectional dimensions of transmission lines in MMIC's are small compared with the wavelengths. This validates the use of the quasi-TEM wave approximation. Then, a new concept of edge-compensated microstrip lines to keep characteristic impedance constant near a substrate edge is introduced to circumvent the proximity effects and to expand the interconnection flexibility of microstrip lines on MMIC substrates. The practical design parameters of the edge-compensated microstrip lines are given in the form of numerical data and simple polynomials for CAD work with a curve-fitting procedure. Results of capacitance measurements are compared with this theory.

II. RECTANGULAR BOUNDARY DIVISION METHOD FOR ESTIMATING SUBSTRATE EDGE EFFECTS

Fig. 1 shows the structure to be treated here. When the microstrip conductor on the top of the substrate is located close to an edge of the substrate and the dimension of the separation S is decreased, the capacitance between the strip and the ground conductor is also decreased. Consequently, the characteristic impedance is increased. Therefore, if this proximity effect is to be circumvented in high-packing-density MMIC's, tolerable sizes for S should be determined before fabrication. The rectangular boundary division method, which has been discussed in a previous paper for treating the proximity effects of the first type, is employed here because each dielectric region in this strucbture is of the rectangular shape suited to this method, as shown in Fig. 2. Substrate thickness h and strip width W are assumed to be sufficiently small compared with wavelengths in order to validate the use of the quasi-TEM wave approximation. The thickness of the strip conductor t is assumed to be negligible in this paper

III. NUMERICAL AND EXPERIMENTAL RESULTS

Fig. 3 shows the estimated proximity effects on the characteristic impedance for the case of GaAs substrate (ε_r=12.9) and alumina ceramic substrate (ε_r=9.7).

The line capacitance (per unit length) was measured to confirm theoretical results on the proximity effects by using a Boonton 72-BD capacitance meter. Experimental parameters of our sample transmission line were ε_r=2.55 (polystyrene), W=4.02mm and h=10.45mm. Measured capacitance values are compared with theoretical ones in Fig. 4. These results agree with our analysis with errors of about 1 percent.

IV. EDGE-COMPENSATED MICROSTRIP LINES

A way to compensate for the proximity effects is to increase the line capacitance by widening the strip conductor width. Hence, we propose "Edge-Compensated Microstrip Lines" (ECM lines) whose structure is as shown in Fig. 1.

The necessary dimensions of the strip width of ECM lines for keeping the characteristic impedance constant can be found by using the above analysis method. Fig. 5 shows the calculated strip width of 50-Ω ECM lines for the case of GaAs and alumina ceramic substrate, where W_0 is defined as the strip width of a classical 50-Ω microstrip line for the same substrate material. Fig. 6 shows the wavelength reduction factor for 50-Ω ECM lines thus designed.

V. APPROXIMATE POLYNOMIAL FORMULAS

The above numerical data on ECM lines can also be expressed in simple approximate formulas by a least-square curve-fitting procedure. The following polynomial formulas give the designed strip width W and the wave length reduction factor λ/λ_0 of 50-Ω ECM lines in terms of the separation S normalized by the 50-Ω microstrip with W_0:

$$\frac{W}{W_0} = \sum_{n=0}^{6} a_n u^n \quad (0.1 \leqq S / W_0 \leqq 5.0)$$

$$\frac{\lambda}{\lambda_0} = \sum_{n=0}^{6} b_n u^n \quad (0.1 \leqq S / W_0 \leqq 5.0)$$

where $u=\log_{10}(S/W_0)$, and the coefficients of the polynomials, a_n and b_n, for GaAs and alumina ceramic substrate, are given in Table I. The errors of these polynomial formulas against the above theoretical results are less than 1 percent.

ACKNOWLEDGMENT

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REFERENCES

[1] R.A. Pucel, "Design consideration for monolithic microwave circuits," IEEE Trans. Microwave Theory Tech., vol. MTT-29, pp.513-534, June 1981.

[2] R.A. Pucel, "MMIC's modeling and CAD-Where do we go from here?", Proc. 16th European Microwave Conf., Sept. 1986, pp.61-70.

[3] E. Yamashita, K.R. Li, and Y. Suzuki, "Characterization method and simple design formulas of MCS lines proposed for MMIC's" IEEE Trans. Microwave Theory Tech., vol. MTT-35, pp.1355-1362, Dec. 1987.

[4] C.E. Smith and R. Chang," Microstrip transmission line with finite-width dielectric," IEEE Trans. Microwave Theory Tech., vol. MTT-28, pp.90-94, Feb. 1980.

[5] E. Yamashita, M. Nakajima, and K. Atsuki, "Analysis method for generalized suspended striplines," IEEE Trans. Microwave Theory Tech., vol. MTT-34, pp.1457-1463, Dec. 1986.

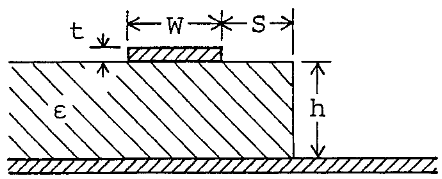

Fig.1 Microstrip lines with a substrate edge (also the structure of edge-compensated microstrip lines to be defined in Sec.IV).

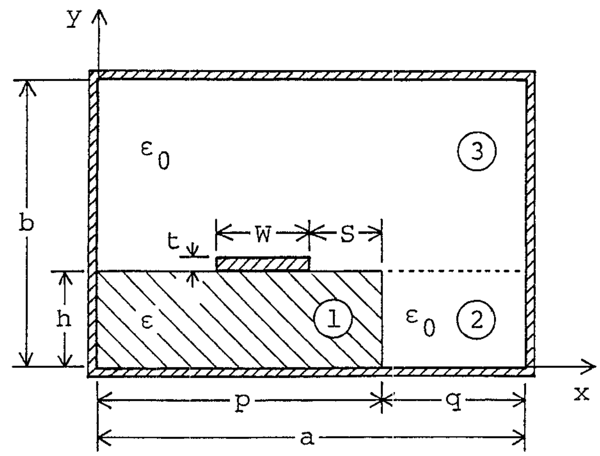

Fig.2 Total structure under study with relevant subareas.

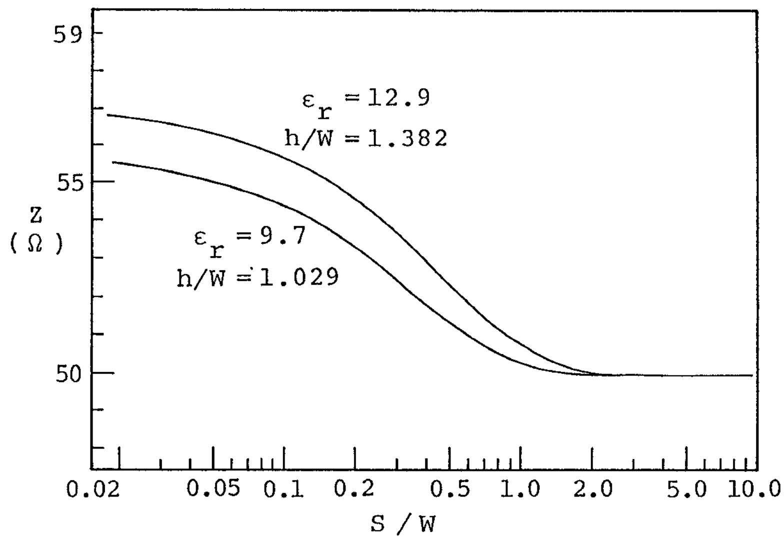

Fig.3
Estimated proximity effects on the characteristic impedance.

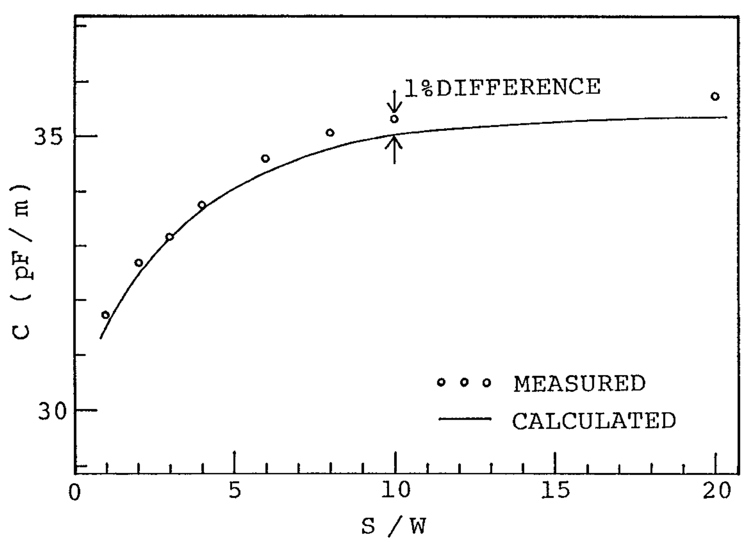

Fig.4
Measured line capacitance values compared with theoretical values for sample line parameters, ε_r=2.55 (polystyrene), W = 4.02mm, and h = 10.45mm.

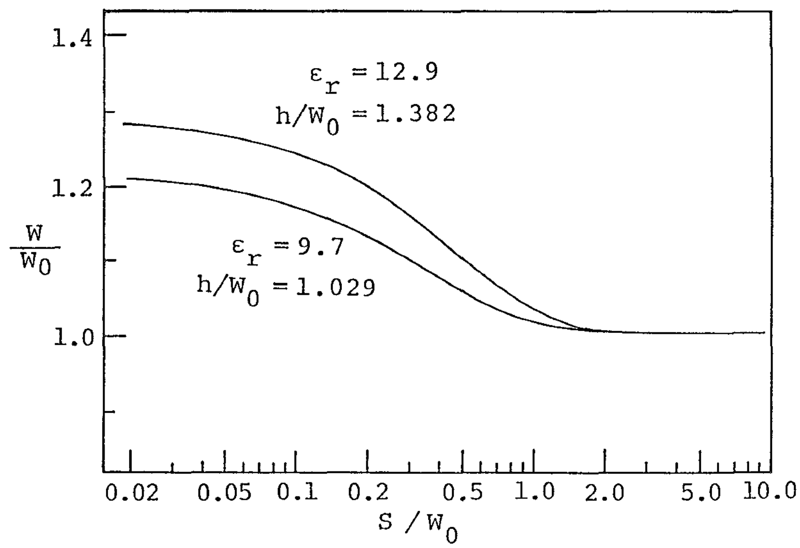

Fig.5
Designed strip width of 50-Ω ECM lines.

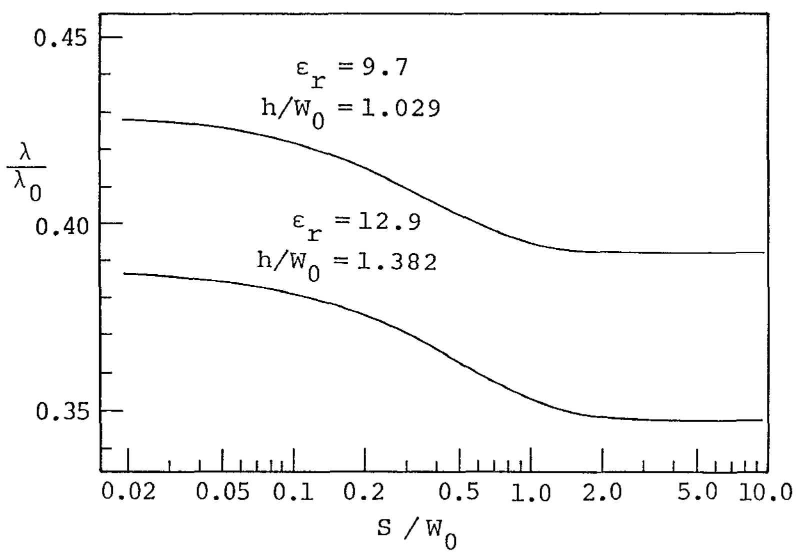

Fig.6
Wavelength reduction factor of 50-Ω ECM lines.

POLYNOMIAL COEFFICIENTS				
	GaAs		Ceramic	
ε_r	12.9		9.7	
h/W_0	1.382		1.029	
i	a_i	b_i	a_i	b_i
0	1.0367	$3.5346 \cdot 10^{-1}$	1.0162	$3.9554 \cdot 10^{-1}$
1	$-1.8228 \cdot 10^{-1}$	$-2.5010 \cdot 10^{-2}$	$-9.8654 \cdot 10^{-2}$	$-1.7792 \cdot 10^{-2}$
2	$1.7147 \cdot 10^{-1}$	$2.2373 \cdot 10^{-2}$	$1.3236 \cdot 10^{-1}$	$2.2627 \cdot 10^{-2}$
3	$1.3289 \cdot 10^{-1}$	$1.8016 \cdot 10^{-2}$	$3.3574 \cdot 10^{-2}$	$6.8338 \cdot 10^{-3}$
4	$-8.0565 \cdot 10^{-2}$	$-1.0253 \cdot 10^{-2}$	$-7.0952 \cdot 10^{-2}$	$-1.2018 \cdot 10^{-2}$
5	$-8.1078 \cdot 10^{-2}$	$-1.0717 \cdot 10^{-2}$	$-2.4336 \cdot 10^{-2}$	$-4.6957 \cdot 10^{-3}$
6	$-1.5946 \cdot 10^{-2}$	$-2.1593 \cdot 10^{-3}$	$2.2125 \cdot 10^{-3}$	$1.9738 \cdot 10^{-3}$

TABLE I
Coefficients of the polynomials in the approximate design formulas of 50-Ω ECM lines.