RIGOROUS HYBRID-MODE ANALYSIS OF MMIC COPLANAR LINES INCLUDING CONDUCTOR BACKING AND VIA HOLES

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ABSTRACT

A modified transverse field-matching method is used to calculate the line characteristics of coplanar structures for MMIC applications. The effects of open circuitry, upper shielding, conductor backing and via holes on the line parameters can be taken into account by changing the reflection coefficients of the boundaries. The method is verified at the examples of open, shielded and conductor-backed coplanar waveguide structures. Good agreement with measurements is obtained. The software is operational on 386-type personal computers.

1. INTRODUCTION

A powerful alternative to microstrip circuitry, coplanar waveguides including conductor backing and via holes are frequently used in open or shielded (M)MIC environments. Although problems concerning effects due to mode conversion [1], dense packaging [2] and conductor backing [3] have been addressed in the open literature, most of the algorithms available are either based on a quasi-static approximation [4] or on a waveguide model with fixed boundary conditions [5]. While the first approach provides reliable data only at frequencies far below the millimeter-wave range, the latter technique usually requires mainframe computer support. Both methods fail to incorporate the flexibility of different boundary conditions for the calculation of line characteristics related to open, conductor-backed, shielded and/or via-hole technology.

Therefore, this contribution presents a flexible yet rigorous hybrid-mode analysis to calculate the line characteristics of coplanar waveguide MMIC structures. By introducing transverse boundary conditions in terms of reflection coefficient matrices [6], a transverse hybrid-mode field-matching procedure can easily be adapted to include open, conductor-backed, shielded and via-hole configurations. Due to this formulation, no artificial boundaries are required for partially open structures. Indeed, the analysis of the *open* coplanar waveguide is the most efficient as far as CPU time and storage requirements are concerned.

2. THEORY

Fig. 1 shows half of the cross-section of the coplanar structure as used for the field theory treatment. The electromagnetic fields in the individual subregions i = 0 - IV

$$\begin{aligned}\vec{E}^i &= \frac{1}{j\omega\varepsilon^i}\nabla\times\nabla\times(A^i_{ex}\vec{e}_x)+\nabla\times(A^i_{hx}\vec{e}_x)\\ \vec{H}^i &= \frac{-1}{j\omega\mu_0}\nabla\times\nabla\times(A^i_{hx}\vec{e}_x)+\nabla\times(A^i_{ex}\vec{e}_x)\end{aligned}\qquad(1)$$

is derived from vector potential components

$$\begin{Bmatrix} A^i_{hx} \\ A^i_{ex}\end{Bmatrix} = \sum_{n=1}^{N}\begin{Bmatrix} \cos\left((2n-1)\frac{\pi}{b}y\right)\left(A^i_n e^{-jk^i_{xn}x} + B^i_n e^{-jk^i_{xn}x}\right) \\ \sin\left((2n-1)\frac{\pi}{b}y\right)\dfrac{-C^i_n e^{-jk^i_{xn}x} + D^i_n e^{-jk^i_{xn}x}}{jk^i_{xn}}\end{Bmatrix} e^{-jk_z z}\qquad(2)$$

where amplitude coefficients A,C and B,D are combined to vectors $\underline{F}$ and $\underline{R}$, respectively, in Fig. 1. In subregion III, the y-dependence of the functions differs slightly from those given in

(2) according to the different boundary conditions. The transverse field-matching procedure applied to the discontinuities at x = -d, -0, +0, t results in a matrix equation in terms of forward and backward travelling waves. A resonance condition is formed by incorporating the reflection coefficient matrices of open and/or short circuits at x=-d and/or x=t+h [6]. The zeros of the system determinant specify the propagation constants. After solving for the related amplitude vectors, the characteristic impedance is calculated using the power-voltage definition.

Compared with other approaches, the major advantage of this method is the accuracy that is achieved while, at the same time, the software is operational on personal computers. Up to thirty expansion terms in the different subregions of the coplanar structure have turned out to yield sufficient convergence behavior. Using this number, the CPU time required to calculate effective permittivity and characteristic impedance values of the fundamental mode varies between five and twenty minutes per frequency sample on a 386-type personal computer. Higher-order modes can also be calculated if required [6].

3. RESULTS

As shown in Fig. 2, extremely close agreement is obtained by comparing the results of this method with those presented in [7]. The slight deviations in effective permittivity and characteristic impedance are due to the finite metallization thickness considered in the present method.

In Fig. 3, it is demonstrated that the static solutions, e.g. [4], are valid only at very low frequencies. Towards higher frequencies, the effective permittivity increases and the characteristic impedance defined by slot voltage and power approaches zero as has also been observed in finline circuits, e.g. [9].

At the example of a conductor-backed coplanar waveguide with via holes for MMIC applications, Fig. 4 shows a comparison between the results of this method and measurements. Excellent agreement is obtained up to 20 GHz. Beyond 20 GHz, the measurement accuracy is degraded due to test pattern coupling and radiation [8].

4. CONCLUSIONS

The modified transverse field-matching technique provides reliable data on the line characteristics of coplanar waveguide structures in MMIC circuits. Open and conductor-backed configurations, which might include via holes, can be calculated without introducing artifical boundaries. The software runs on modern personal computers and does not require mainframe computer support. Good agreement with measurements is obtained as is demonstrated at the example of a conductor-backed structure with via holes.

5. REFERENCES

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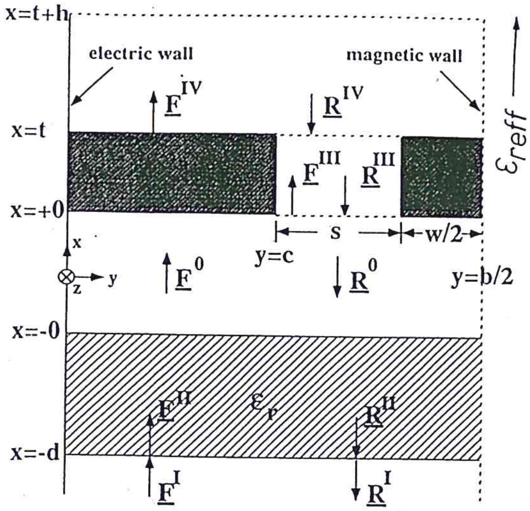

Fig. 1 Cross-section of coplanar waveguide (only one half shown).

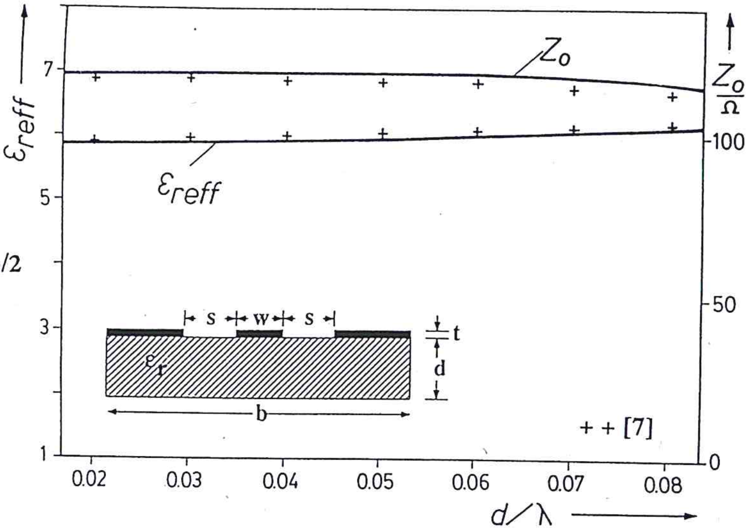

Fig. 2 Line characteristics of an open coplanar waveguide versus normalized frequency (++ [7], —— this theory); b=4mm, d=1mm, t=5μm, w=300μm , s=250μm, ε_r=11.

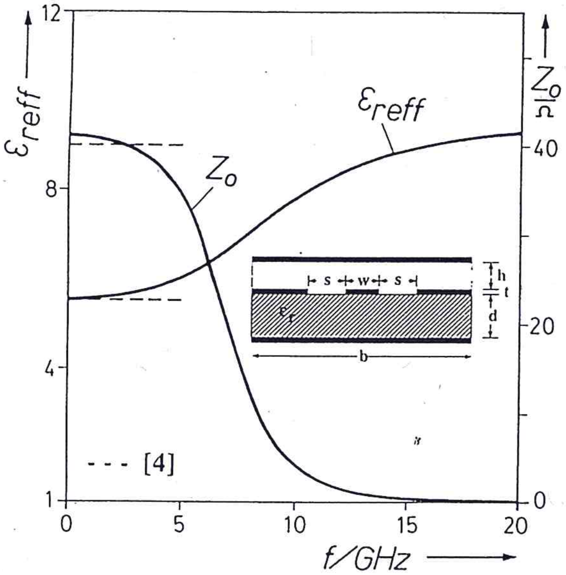

Fig. 3 Comparison of results using this theory (solid lines) with the static analysis [4] (dashed lines) for a shielded coplanar waveguide; b=10mm, d=w=h=1mm, t=2μm, s=0.5mm, ε_r=10.

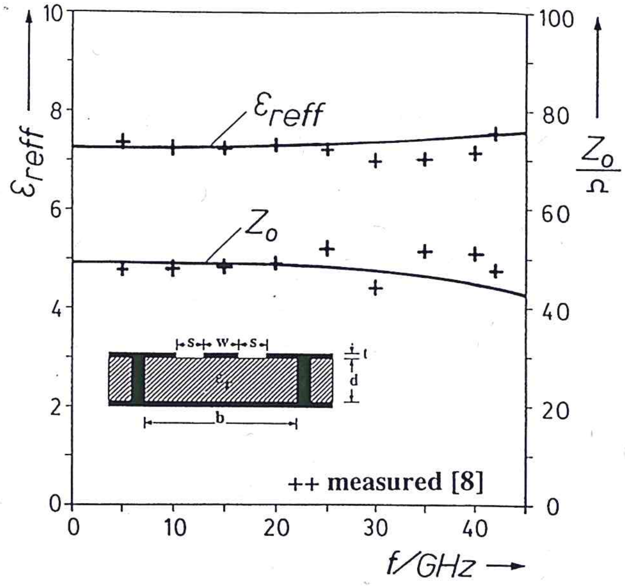

Fig. 4 Line characteristics of a conductor-backed coplanar waveguide with via holes for MMIC applications (++ measured [8], —— this theory); b=1mm, d=100μm, t=1.5μm, w=51μm , s=50μm, ε_r=12.9.