Impedance Calculation for the Microshield Line

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Abstract— **The microshield line, a new type of monolithic planar transmission line, is investigated analytically, highlighting its features with respect to other conventional planar lines. The characteristic impedance of the new line is obtained using two different techniques: the computationally intensive point matching method (PMM) and the analytical conformal mapping method (CMM). In the latter method, a CAD-oriented analytical expression, in terms of all finite line dimensions, is obtained using conformal mapping techniques. It is shown that the results of both methods agree very well which verifies both analyses. In addition, the effect of finite-extent ground planes on the characteristic impedance is demonstrated.**

I. Introduction

Recently, the microshield line, a new type of monolithic planar transmission line appropriate for circuit or array applications, has been proposed [1], [2]. This line may be considered as an evolution of the conventional microstrip or coplanar structure and is characterized by pure TEM propagation and zero dispersion when operating in the single mode frequency range [1]. In this configuration, the ground plane has been deformed from its original planar form to totally or partially surround the inner conductor which still has the form of a printed strip (see Fig. 1). One of the advantages of the microshield line is the ability to operate without the need for via-holes or the use of air-bridges for ground equalization. Furthermore, due to the many available parameters in design, a wide range of impedances may be achieved.

The fabrication of microshield circuits is dependent on the thin dielectric membrane technology and the anisotropic etching of the supporting wafers. An Si membrane is a 3-layer SiO_2–Si_3N_4–SiO_2 structure which must be slightly in tension to yield flat and rigid self-supporting characteristics [3]. After the development of the three-layer structure, the membranes are fabricated in two steps. First, an opening in the silicon-nitride layers is defined on the back of the wafer, and then the silicon is etched until a transparent membrane appears. Once the membranes are fabricated, it is easy to lithographically define several different microshield geometries. Fig. 1(a) shows one way of fabricating the microshield line in which the two Si wafers are attached together to form the shielding microcavity. It should be noted that the capacitance between the upper ground and lower ground metallizations (see Fig. 1(a)) is very high, which essentially presents an RF short at high frequencies. Fig. 1(b) shows a photograph of a microshield line filter as seen from the bottom (with the shielding ground plane removed). The cavity dimensions can be chosen such that no higher order modes are excited at the desired operating frequency.

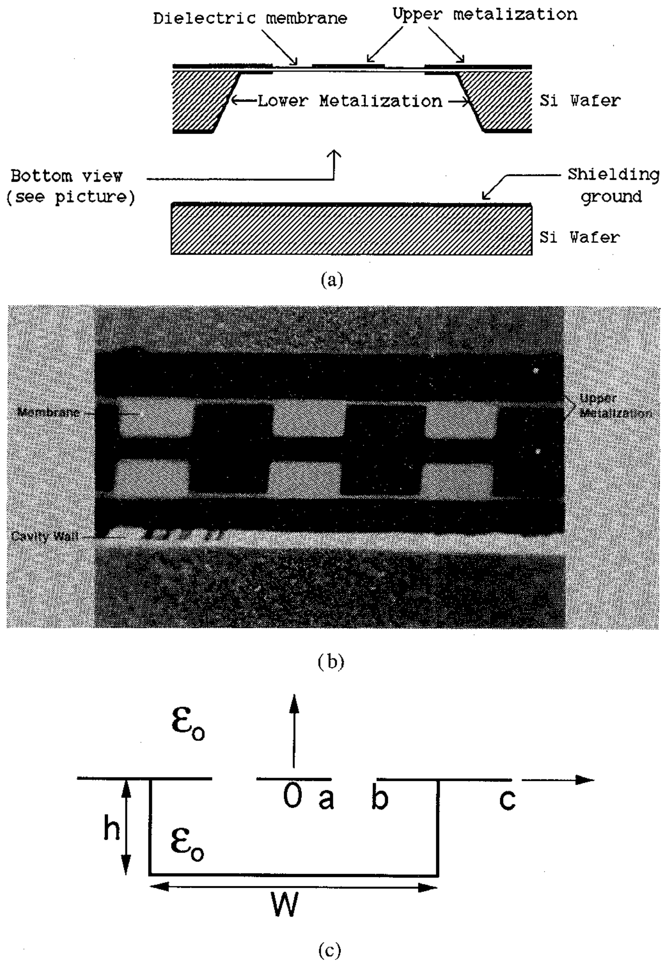

Fig. 1. (a) One way of fabricating the microshield line. (b) Bottom view of a microshield line filter. (c) Simplified cross sectional view suitable for theoretical formulation.

In this letter, two techniques are used to obtain the characteristic impedance of the microshield line: a computational technique based on the point matching method (PMM) [4] and an analytical one based on the conformal mapping method (CMM). A CAD-oriented closed form expression, that can be easily evaluated, is derived using the CMM. This expression gives values of the characteristic impedance that are in very good agreement with those obtained using the PMM.

II. Formulation

For the characteristic impedance evaluation, the cross section of the microshield line is simplified as shown in Fig. 1(c).

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In this figure, the effect of the membrane is neglected since its thickness ($\simeq 1.4\ \mu$m) is very small compared to the waveguide height. In the PMM [4], first, Laplace's equation is solved in the air and the waveguide regions. Then, the boundary conditions in the plane of the slot aperture are enforced that result in a matrix equation that can be solved to give the unknown potential distribution. Finally, the capacitance per unit length and consequently Z_0 can be computed from the derived potential. One disadvantage of the PMM is that it is computationally intensive, which makes it helpful to have an analytical formula for the evaluation of Z_0 of the microshield line. Such a formula can be easily obtained using the CMM as will be discussed next.

The CMM has been widely used to obtain analytical formulas for the quasi-TEM parameters of the coplanar waveguide (CPW) structures [5]. For the microshield line (Fig. 1(c)), the overall capacitance per unit length is the sum of the capacitance of the upper half plane (open air region) and the lower half plane (the waveguide region). The former capacitance, C_a, can be easily obtained using the following formula [5]:

$$C_a = 2\,\epsilon_0 \frac{K(k)}{K(k')}, \tag{1}$$

where

$$k = \frac{a}{b}\sqrt{\frac{1-b^2/c^2}{1-a^2/c^2}}$$
$$k' = \sqrt{1-k^2}$$

and $K(k)$ is the complete elliptic integral of the first kind [6]. The capacitance due to the waveguide region, C_w, can be evaluated through a suitable sequence of conformal mappings. First, the interior of the rectangle is mapped onto an upper t half-plane [7] and then back onto a rectangular domain from which the capacitance can be evaluated [5]. After some lengthy manipulations, the following formula for C_w can be obtained

$$C_w = 2\,\epsilon_0 \frac{K(\zeta)}{K(\zeta')} \tag{2}$$

where

$$\zeta = \frac{sn(a/\beta)}{sn(b/\beta)}$$
$$\zeta' = \sqrt{1-\zeta^2}$$
$$\beta = \frac{W}{2K(\gamma)}$$
$$\gamma = \left[\frac{e^{\pi W/2h} - 2}{e^{\pi W/2h} + 2}\right]^2$$

In these equations, $sn(\theta)$ is the Jacobian elliptic function which can be evaluated using the routine in [8]. After evaluating (1) and (2), the characteristic impedance Z_0 can be derived as

$$Z_0 = \frac{1}{v_o(C_a + C_w)} \tag{3}$$

where v_o is the speed of light in free space. The above TEM analysis, using either PMM or CMM, should provide the exact characteristic impedance of the microshield line as long as the line operates in the single mode frequency range.

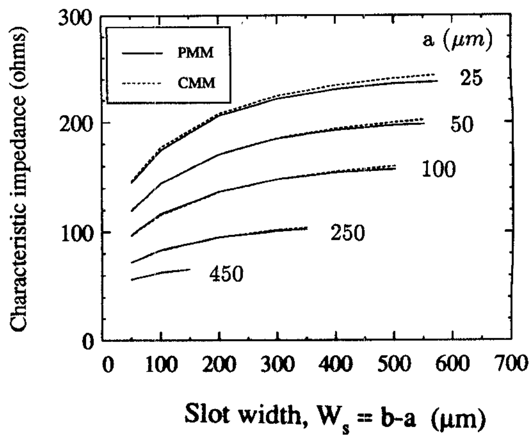

Fig. 2. Characteristic impedance of a microshield line with $W = 1200\ \mu$m, $h = 400\ \mu$m and $c = 1800\ \mu$m.

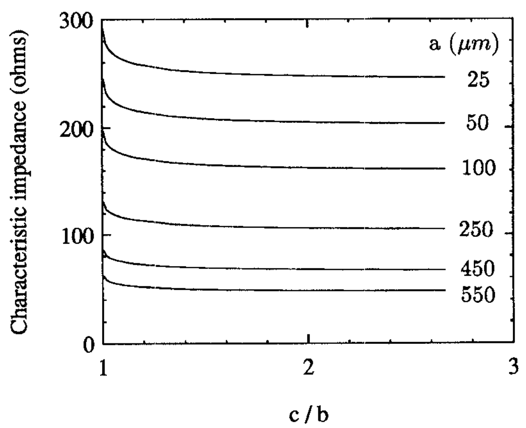

Fig. 3. Effect of finite ground plane extent on the characteristic impedance of a microshield line with $W = 1200\ \mu$m, h $= 400\ \mu$m and $b = 600\ \mu$m.

III. Results

Fig. 2 shows Z_0 of a microshield line, evaluated using PMM and CMM, as a function of slot width, W_s, and with the center conductor width as a variable. As shown, the results obtained by the two methods differ by less than 3%, which validates the derived closed form analytical expression. It should be mentioned that for small slot width ($W_s \leq 100\ \mu$m) and/or center conductor width, the size of the matrix involved in the PMM becomes very large in order to insure convergence.

Fig. 3 shows the effect of finite extent ground planes on the characteristic impedance. It can be seen that finite extent ground planes have negligible effect on Z_0 as long as $c/b > 2$. This is an advantage of the microshield line over the conventional CPW where c/b should be larger than 4 to insure that the variation is negligible [5].

IV. Conclusion

The microshield line characteristic impedance has been obtained using two techniques: the point matching method (PMM) and the conformal mapping method (CMM). The analytical closed form expression derived using CMM is shown to agree very well with data obtained by PMM. The effect of finite extent ground planes on the characteristic impedance has been demonstrated. It has been found that small ground planes suffice to insure negligible effect on the line characteristics.

V. Acknowledgment

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