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Analysis for Arbitrary Metallization Thickness of RF MEMS Coupled Microstrip Lines and Microstrip Lines

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Abstract: This paper describes a method to analyze arbitrary metallization thickness on a coupled microstrip lines and microstrip lines for RF MEMS passive device design. Using conformal mapping technique and magnetic-wall, quasi-static parameters closed-form expressions for metallization thickness of coupled microstrip lines and microstrip lines are determined. They are found to be accurate compared with the Agilent ADS LineCalc tool. By using this method, the even-odd mode impedance of coupled microstrip lines and impedance of microtrip lines for arbitrary metallization thickness can be obtained.

1. Introduction

Parallel coupled microstrip lines and microstrip lines are widely used in directional couplers, filters, and delay lines[1]. Their quasi-static impedances and effective permittivity are the most important parameters in the analysis and design of the related components. But some existing analytical methods[2]and numerical methods [3] to solve such a problem are only limited to zero metallization thickness of microstrip line. Recently, growing interest in radio frequency microelectromechanical system (RF MEMS) passive devices tend to require that height of the central strip and width are comparable, or higher (high-aspect ratio) for microstrip circuit design [4]. In a word, in RF MEMS passive circuits, maximum metallization thickness is up to 10 times height comparing the strip width so that the effect of thickness cannot be neglected for accurate design. Even though various design equations for coupled microstrip lines are available in the literature, but accuracy of those method is still unsolved problem. They only consider finite metallization thickness which is much less than width [5].

This paper introduces a generalized approach to the analysis of coupled lines of arbitrary metallization thickness based on the robust and efficient numerical solutions provided by the Schwarz-Christoffel (SC) toolbox [6][7]. The SC conformal formula, a special conformal transformation devised for polygonal regions, has been widely applied to coaxial structures, strip lines, and coplanar waveguides (CPWs) in order to get closed-form expressions for the line characteristic parameters, usually in terms of complete elliptic integrals.

2. Analytical analysis of microstrip line with arbitrary metallization thickness

Fig. 1 (a) shows the geometry of coupled microstrip lines.The structure consists of two identical signal strips of width w with a gap s on a dielectric substrate of thickness h and permittivity $\varepsilon_0\varepsilon_r$ on an infinite ground plane. The signal strips are assumed to be infinitely long, and all the conductors are perfectly conducting. Under the above assumptions, the structure supports two normal quasi-TEM modes, i.e., even mode and odd mode. The analysis method is based on isolating the odd and even modes by assuming the electric wall in the case of the odd modes and a magnetic wall for the even modes. We can obtain Fig.1 (b). In even mode, the y-axis is magnetic wall. In odd mode, the y-axis is electric wall.

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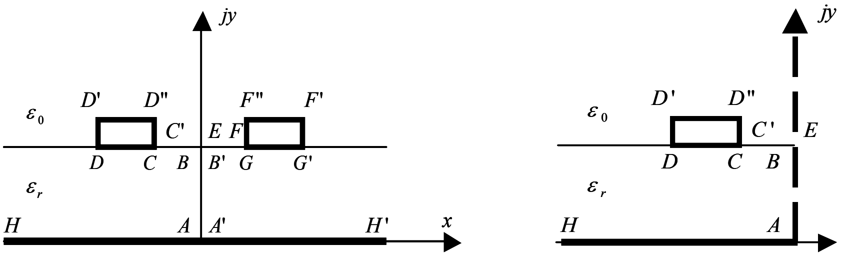
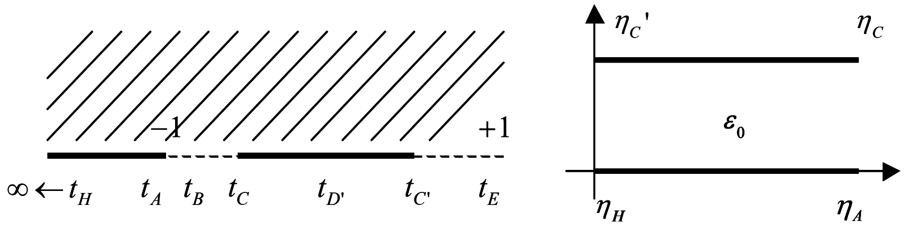


(a) (b)

Fig.1 (a) Geometry of coupled microstrip lines ; (b)even modes

The following Schwarz-Christoffel transformation will map the interior of polygonal region *H-A-B-C-D-D'-D''-C'-E-H'* in z-plane into the upper half of *t*-plane, where the corresponding points in t-plane are labeled, $0 < t_A < t_B < t_C < t_{C'} < t_E$, C_1 is a complex constant to be determined, as shown in Fig.2 (a), In odd mode, $t_A \rightarrow t_B$ is solid(electric wall) line, $t_E \rightarrow \infty$ is solid line.



(a) (b)

Fig.2 (a) Mapping of coupled microstrip lines into canonical plane and (b) final transformation into a rectangular region (parallel-plate capacitor)

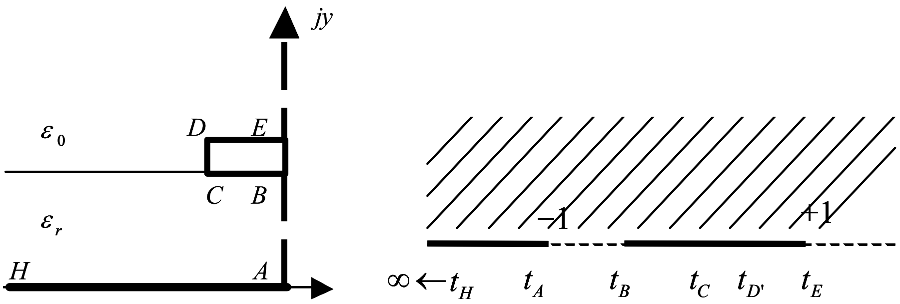
By means of the SC mapping equation (1), and three pre-vertices can be chosen arbitrarily (the SC toolbox imposes t_A= -1, t_E = +1, and $t_H = \infty$), thus yielding a parameter problem with five pre-vertices unknowns. The determination of these real parts requires the solution of a system of five nonlinear equations, involving the computation of seven hyper-elliptic integrals whose singular end points are the unknown pre-vertices. The function `hplmap` of the SC toolbox provides an accurate solution of the parameter problem, computing the constant C_1 and the pre-vertices t_A … t_E . Eventually, the strips in the canonical domain are transformed via an inverse closed-form SC mapping into the parallel plates of a rectangular capacitor in Fig.2 (b). Therefore, the exact quasi-static capacitance, and characteristic impedance of the microstrip line can be computed as follows.

$$\frac{dt}{dz} = C_1 \int \frac{\sqrt{(t-t_D)(t-t_{D''})(t-t_{D'})}}{\sqrt{(t-t_A)(t-t_B)(t-t_{C'})(t-t_E)}} dt \tag{1}$$

$$Z_e = \frac{120\pi}{\sqrt{\varepsilon_{re}}} \frac{K'(k_e)}{K(k_e)} \text{ , and } Z_o = \frac{120\pi}{\sqrt{\varepsilon_{ro}}} \frac{K'(k_o)}{K(k_o)} \tag{2}$$

where $k_e = \dfrac{t_{C'} - t_C}{t_{C'} - t_A}, k_o = \dfrac{(t_{C'} - t_C)(t_B - t_E)}{(t_B - t_{C'})(t_C - t_E)}, K(k)$ is the complete elliptic integral of the first kind. ε_{re} and ε_{ro} can be obtained from the analysis of coupled microstrip line by conformal transformation method[8].

Microstrip lines, as is similar with even mode of coupled microstrips lines, analysis by only setting $s = 0$. The microstrip impedance is half the even mode of coupled lines, as Fig.3.

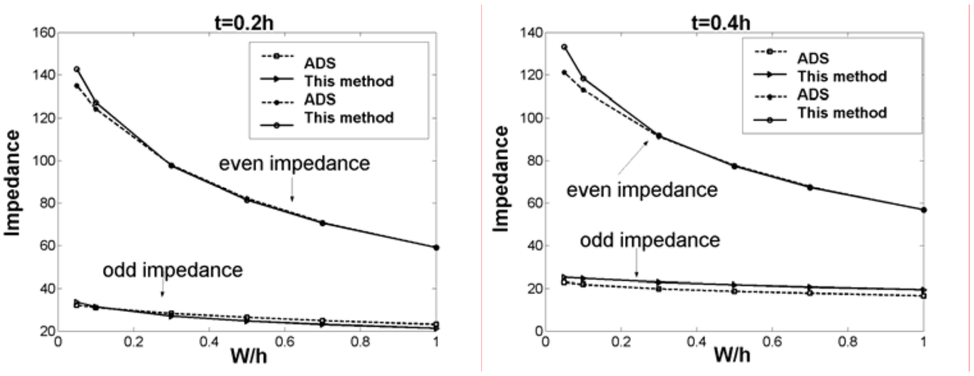


a) b)

Fig.3 The equivalent structure of microstrip; b) Mapping of coupled microstrip lines into canonical plane

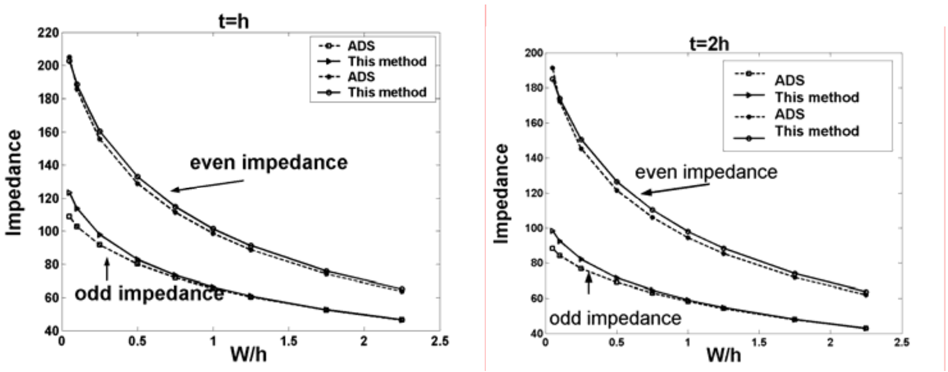
3. Impedance calculation

The expressions derived are calculated for the characteristic impedance equations in given dimensions and dielectric substrate in both cases. For the purpose of comparison, we compute the impedances with Agilent ADS simulation LineCalc tool. Fig.4 and Fig.5 give the calculation comparison of coupled microstrip lines. Fig.6 give comparison of microstrip lines



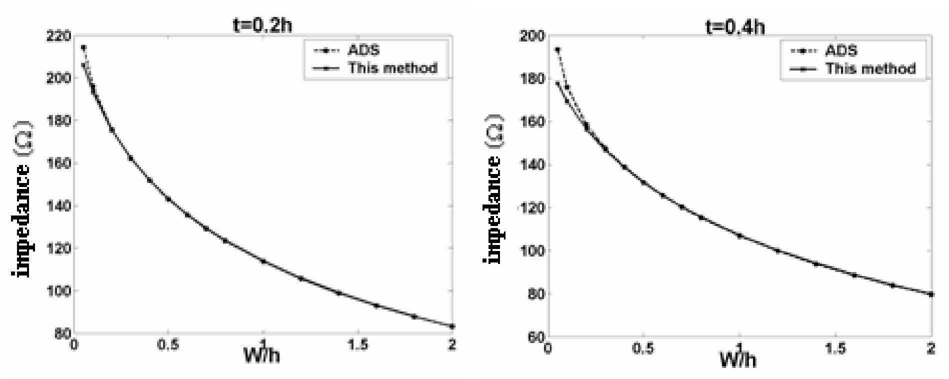
(a) t=0.2h (b) t=0.4h

Fig.4 Comparison of impedance calculation with ADS for ε_r=10.0 and s/h=0.2



(a) t=h (b) t=2h

Fig.5 Comparison of impedance calculation with ADS for ε_r=2.35 and s/h=1.0



a) t=0.2h b) t=0.4h

Fig.6 Comparison results with method of SC and Aglient ADS t=0.2h,t=0.4h,ε_r=1

As results of these figures, the formulas are not recommended for case with small high-aspect ratio (*W/h* <0.1). In the case of ε_r=10.0 and *s/h*=0.2 and *W/h* >0.2, calculated even impedance accuracy by this method is t within 0.5%, the odd impedance is within 4%. For the case of ε_r=2.35 *s/h*=1.0 and *W/h*>0.5, the even impedance is within 2.7%, the odd impedance is within 0.5%.

After comparing with the well-recognized results generated by numerical methods, they have been found to be accurate. But for *W*/*h* < 0.1 case, there exist some errors compared with Agilent ADS LineCale. The following two reasons will give the answer: 1) There are no accurate solutions to effective permittivity. 2) One more geometrical parameter is involved in modeling the coupled counterpart as compared with a single microstrip line. However, it is an efficient and enough accurate method to analyze arbitrary metallization thickness of coupled microstrip lines, especially for RF MEMS passive circuits.

4. Conclusion

Parallel-coupled microstrip lines with arbitrary metallization thickness have been analyzed using mixed techniques: modified conformal mapping technique and a magnetic-wall approximation. The significant expressions for the accurate calculation of quasi-static parameters, i.e., even- and odd-mode characteristic impedances are obtained. This approach provides more accurate analysis for RF MEMS passive circuit design.

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