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Quasi-static Analysis on the Effect of the Finite Metal with the Anisotropic Grooved Dielectric in Microstrip Lines

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Abstract: In this paper, we presented the quasi-static characteristics of novel microstrip lines with anisotropic grooved dielectric in finite metal. A quasi-static mode-matching method has been used to analyze this new structure and the simulation results are validated through comparison with other available results. The results in this paper show that it is possible to control the propagation characteristics of microstrip lines with the use of anisotropic grooved dielectric in finite metal. Also anisotropic grooved dielectric in microstrip line can be newly added to the design parameters of high performance three dimensional monolithic microwave circuits and other microwave applications.

Keywords: Quasi-static analysis, Finite metal, Grooved dielectric, Microstrip line

1. Introduction

In conventional high frequency planar circuit design methodologies the thickness of the metallization has been generally ignored with reasonable accuracy. However, with the advent of micro-electro-mechanical system(MEMS) fabrication techniques the finite metallization thickness becomes one of the important factors that can affect the propagation and attenuation characteristics of planar waveguides, especially in high-density MEMS's for microwave and millimeter-wave frequency applications.

Improvements in fabrication of high-performance complex components in these bands, the design of MEMS's requires simulation tools with higher accuracy which can take into account finite-thickness planar transmission lines[1-3]. In addition to considering of finite metallization thickness, new type of transmission line which have dielectric groove in finite metal conductor is proposed in this paper, for the first time, for the various control of propagation characteristics in single transmission line.

Until recently a few full-wave approaches have been developed to analyze the finite thickness microstrip lines for applications at high frequency region. Most of the analyses are, however, based on quasi-static formulations, since results are acceptably accurate in the frequency region and easy to obtain[3]. Among the many possible methods suitable for rigorous analysis of the structures with metallization thickness, the mode-matching method is chosen in this works, since the formulation is simple and straightforward and there is no need to evaluate integrals and multiple iterations[3]. In this paper, the mode-matching method[4] which can provide a simple approach to the quasi-static analysis is used to analyze the novel single transmission lines with an anisotropic dielectric groove in finite metal conductor, as shown in Fig. 1, for the three dimensional microwave circuit applications.

2. Formulations and Simulation Results

The single transmission lines with grooved finite

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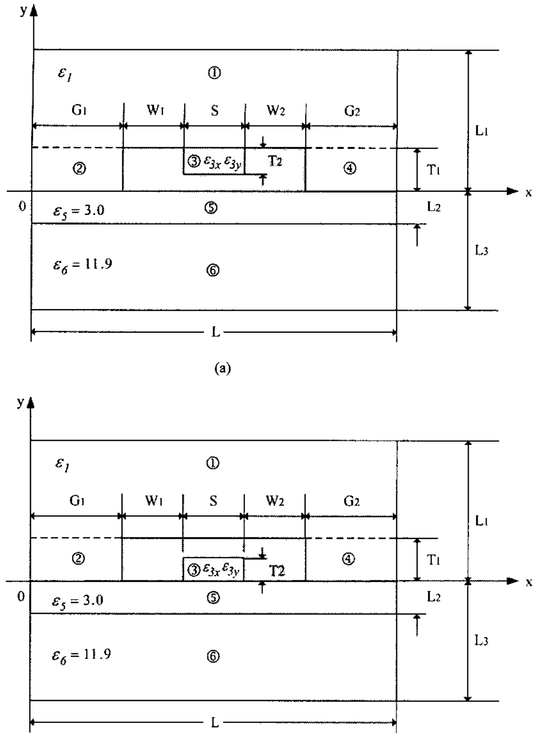

(a)

(b)

Fig. 1. Cross section of the microstrip line with a grooved dielectric in finite metal.

metal fabricated on a two-layered dielectric substrate are shown in Fig. 1. In the analysis of the structure the two-dimensional cross-section is divided into six regions, and all of the metals in the structure are assumed to be perfectly conducting, including the with shielding box which must be placed far enough to minimize the electromagnetic interactions which signal lines. For the structure the potential functions are expressed in terms of Fourier-sine series satisfying Laplace's equation and boundary conditions. For the Fig. 1(a),

$$\phi_1 = \sum_{i=1}^{N_1} A_i\left[e^{\frac{i\pi(y-L_1)}{L}} - e^{-\frac{i\pi(y-L_1)}{L}}\right]\sin\frac{i\pi x}{L} \tag{1}$$

$$\phi_2 = \frac{V_1}{G_1}x + \sum_{j=1}^{N_2}\left[B_j e^{\frac{i\pi y}{G_1}} + C_j e^{-\frac{i\pi y}{G_1}}\right]\sin\frac{j\pi x}{G_1} \tag{2}$$

$$\phi_3 = V_1 + \sum_{k=1}^{N_3} D_k\left[e^{\frac{k\pi(y-T_1)}{S}} - e^{-\frac{k\pi(y-T_1)}{S}}\right] \sin\frac{k\pi[x-(G_1+W_1)]}{S} \tag{3}$$

$$\phi_4 = \frac{V_1(L-x)}{G_2} + \sum_{i=1}^{N_4}\left[F_l e^{\frac{l\pi y}{G_2}} + G_l e^{-\frac{l\pi y}{G_2}}\right] \sin\frac{l\pi[x-(L-G_2)]}{G_2} \tag{5}$$

$$\phi_6 = \sum_{i=1}^{N_1} J_i\left[e^{\frac{i\pi(y+L_3)}{L}} - e^{-\frac{i\pi(y+L_3)}{L}}\right]\sin\frac{i\pi x}{L} \tag{6}$$

where V_1 are the initial potential applied to strip and the potential expansion series are truncated with different mode numbers of N_1, N_2, N_3 and N_4 in each region. By employing the boundary conditions, the coefficients $\{B_j, C_j, D_k, F_l, G_l, H_i, I_i\}$ are derived as dependent variables on the coefficients $\{A_i, J_i\}$. The characteristic impedances and effective dielectric constants of the structure are determined by calculating the electric charges on each strip$^{5)}$. The formulation procedures for the Figure 1(b) are omitted because they are similar as those of Figure 1(a).

To provide the validity of the calculated results presented in this paper, the same procedure is also applied to the shielded single microstrip line considered in$^{3)}$. Comparison is made between our calculated results and close agreement with the published results has been obtained. Table 1 lists the calculated characteristic impedance of the shielded single microstrip line with different combinations of both metallization thickness and width.

In Table 2, characteristic impedances and effective dielectric constant of single microstrip line with two substrate layers, the same dimensions of the structure analyzed in this paper, are compared between the results of commercial software$^{8)}$ and this paper, and close agreement has been obtained, also.

Figure 2 shows the characteristic impedances and effective dielectric constants of the proposed single transmission lines in Figure 1(a) with different combinations of both dielectric property of groove ε_{3x}

Table 1. Calculated characteristic impedances of single microstrip line considered in 3)

W_1+S+W_2(*mm*)	T_1(*mm*)	Ref. [3](Ω)	Ref. [6](Ω)	Ref. [7](Ω)	this paper(Ω)
0.2	0.1	108.07	108.53	108.96	109.06
0.2	0.2	91.04	91.20	92.44	89.92
0.4	0.1	79.18	80.32	80.92	80.00
0.4	0.2	66.84	67.20	67.62	66.29
0.6	0.2	49.42	50.02	50.54	49.37

$\epsilon_{3x}=\epsilon_{3y}=0.0$, $\epsilon_5=1.0$, $\epsilon_6=0.0$, $T_2=0$, L=1 *mm*, $L_1+L_3=1$*mm*, $L_1=L_3-T_1$, $W_1=W_2$, $L_2=0$

Table 2. Calculated characteristic impedances and effective dielectric constant of single microstrip line with two substrate layers

W_1+S+W_2=290 *μm*, T_1=50 *μm*	Ref. [8]	this paper
Characteristic impedance Z(Ω)	57.16	57.38
Effective dielectric constant	5.58	5.59

$\epsilon_{3x}=\epsilon_{3y}=0.0$, $\epsilon_5=3.0$, $\epsilon_6=11.9$, $T_2=0$, L=2.29 *mm*, $L_1=1$*mm*, $L_2=10$μm, $L_3=510$μm

and ε_{3y} for the dielectric groove depth T_2, respectively. The dielectric properties of the substrates are assumed as $\varepsilon_1=\varepsilon_0$, $\varepsilon_5=3.0\varepsilon_0$ and $\varepsilon_6=11.9\varepsilon_0$ for the structure, which are polymide and silicon substrate of wafer for assuming of MEMS fabrication, respectively. The dielectric material with dielectric constant ε_{3x} and ε_{3y}, groove depth T_2 and width S are deposited on metal strip with dimensions $W_1=W_2$, $G_1=G_2=L_1=$ 1 *mm*, and $L_2=10$ *μm*, $L_3=510$ *μm* for the structure in Figure 1(a). The grooved material is assumed to be a homogeneous anisotropic dielectric with z-cut $LiNbO_3$ crystal of which the anisotropic dielectric constants are 43 and 28 in the *x* and *y* direction, respectively. To implement the Figure 1 structures, the liquid polymide material can be used as the dielectric groove for easy fabrication process. After coating and hardening of liquid dielectric, unnecessary parts of dielectric material can be removed for groove implementation and metal plating can be applied to the dielectric groove for finite metallization. In the figure, the grooved dielectric height T_2 has been changed from 0 μm to 40 μm, while the relative ratio of $W_1(=W_2)/S$ has been varied from 2.4 to 1.1 and the results are also compared with the results for the isotropic dielectric groove with $\varepsilon_{3x}=\varepsilon_{3y}=10.0$. As the grooved dielectric height increases, so the characteristic impedances and effective dielectric constants decreases. The results show that the effective dielectric constants and characteristic impedances can be slightly controlled as the dielectric property, width and depth of the dielectric groove in finite metal conductors.

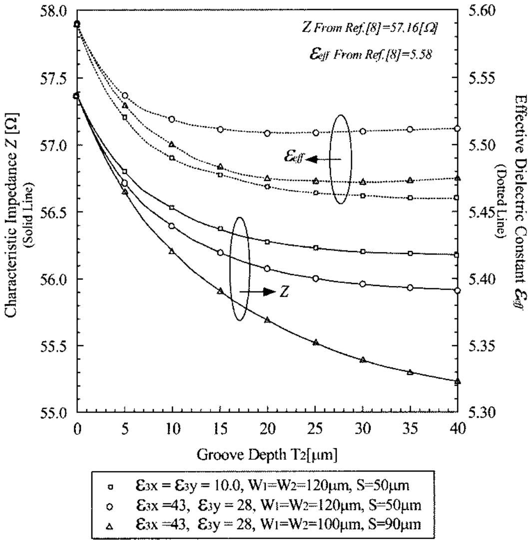

Fig. 2. Characteristic impedances and effective dielectric constants as a function of dielectric groove depth T_2 in Figure 1(a).

The characteristic impedances and effective dielectric constants of the proposed single transmission lines in Figure 1(b) with different combinations of both dielectric property of groove ε_{3x} and ε_{3y} for the dielectric groove depth T_2 are presented in Figure 3 for the same dimensions of Figure 2, respectively. Calculated quasi-static results of microstrip line with including grooved dielectric in finite metal has more interesting compared to the results of Figure 1(a). As

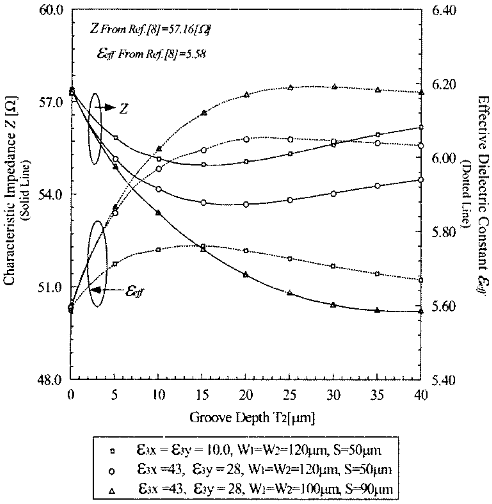

Fig. 3. Characteristic impedances and effective dielectric constants as a function of dielectric groove depth T_2 in Figure 1(b).

the grooved dielectric height increases, so the characteristic impedances decreases but effective dielectric constants increases. For example, it can be seen that the difference between the minimum and maximum values of the characteristic impedances and effective dielectric constants due to the properties of dielectric groove is not negligible value, i.e., approximately 12.5% in characteristic impedances and 11.1% in effective dielectric constants. The results are new evidence that the properties of dielectric groove in finite metal conductors such as dielectric constant and size affects the propagation characteristics of single transmission line and will be one of the new design parameters.

3. Conclusion

In this paper, two type novel structure of microstrip line having anisotropic grooved dielectric in finite thickness conductor has been presented for the first time. Rigorous calculation have been performed based on quasi-static mode matching technique, which could be applied for arbitrary two-dimensional geometries. The characteristic impedances and effective dielectric constants are presented as a function of the groove depth in finite metal lines. This newly proposed structure in this paper is attractive component in many microwave circuits and can be applied to other similar applications.

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