DISPERSION PROPERTIES OF MULTICONDUCTOR MICROSTRIP LINES IN SUSPENDED SUBSTRATES AND INVERTED MICROSTRIP LINES BY USING MODAL ANALYSIS

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ABSTRACT

In this paper a full wave modal analysis is performed on three symmetric parallel-coupled microstrip lines in suspended substrates structures and inverted microstrip lines. The numerical procedure based on the modal analysis, is formulated to compute all the frequency-dependent normal mode parameters of three-coupled microstrip lines structures. These parameters include phase constant, modal impedances, current and equivalent voltage eigenvector matrices and the conductor and dielectric losses of the coupled three lines for all three modes. A perturbation technique is combined with the modal analysis to evaluate conductor and dielectric losses in microstrip and inverted microstrip in the metallic enclosure. The formulas take into the account the finite thickness of the strip conductor for conductor loss calculation.

INTRODUCTION

Spectral domain formulation has been widely used in recent years for computing the propagation constant and characteristics impedance of various microwave and millimeter-wave propagation structures and is presented in [1]-[4]. For the case of symmetric coupled microstrip lines, work has been done on the computation of the even and odd mode parameters [1].

In addition, attempts have been made to compute the normal mode parameters of suspended substrate single microstrip line and inverted microstrip line [5]-[6]. In this paper, the analysis of three symmetric parallel-coupled microstrip lines in suspended substrates structures and inverted microstrip lines are presented first time. All the characteristics normal mode parameters are obtained from the full wave modal analysis [2]-[3].

Starting from the known hybrid mode formulations of the single and multiple boundary Green's function interrelating current and electric fields at all the interfaces, a comprehensive procedure to compute all the frequency-dependent normal mode parameters of multiconductor microstrip line in suspended substrate is formulated. Here the results of shielded suspended substrate three-lines microstrip and inverted microstrip structures are presented. The conductor and dielectric loss are also presented for three coupled microstrip lines in suspended substrate and inverted microstrip lines. For the conductor loss the perturbation formula has been used. The field coefficient is calculated using zero thickness and then by using the perturbation theory, conductor loss is computed for finite thickness on all the four walls of strips [7].

THEORITICAL FORMULATION

The numerical technique used to compute the phase constants for the dominant hybrid mode is full wave modal as presented in [2]. In the hybrid mode analysis all the field components are constructed in terms of x-components of electric and magnetic fields in each region, which are expanded in terms of modal fields with unknown coefficients

$$\sum_{k=1}^{\infty} c_k \sum_{n=0}^{\infty} p_n G_{11} L_{2n}^{k} L_{2n}^{m} + \sum_{k=1}^{\infty} d_k \sum_{n=0}^{\infty} q_n G_{12} L_{1n}^{k} L_{2n}^{m} = 0$$
$$\sum_{k=1}^{\infty} c_k \sum_{n=1}^{\infty} p_n G_{21} L_{2n}^{k} L_{1n}^{m} + \sum_{k=1}^{\infty} d_k \sum_{n=1}^{\infty} q_n G_{22} L_{1n}^{k} L_{1n}^{m} = 0 \quad (1)$$

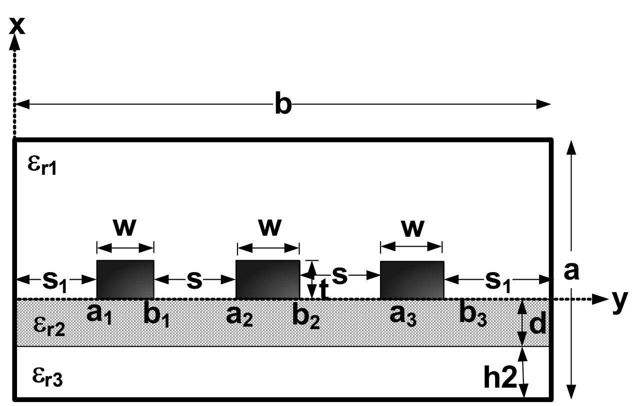

Fig. 1: Cross-section of three coupled lines in shielded suspended substrate structure

The propagation constants are evaluated by the above (1) applying the Galerkin method to the transformed Green's function matrix relating the currents and electric fields at various boundaries of the structure and solving for the roots of the determinant [2]. Tangential components of the electric field at the interface are related to the surface currents by the Green's dyadic called the impedance matrix. Expansion of surface currents in a set of basis functions and imposition of the condition that the tangential electric fields must be zero on the strips leads to a determinantal equation for unknown eigenvalues β.

The set of basis functions used in this analysis are sinusoidal and expressed as follows:

$$L_{2n} = \sum_{m=1}^{\infty} c_m L_{2n}^m = \sum_{m=1}^{\infty}\sum_{i=1}^{P} \int_{S_i}^{S_i+W_i} c_{mi} I_z(y)\cos(\alpha_n y)\,dy\,; \quad (2) \qquad L_{1n} = \sum_{m=1}^{\infty} d_m L_{1n}^m = \sum_{m=1}^{\infty}\sum_{i=1}^{P} \int_{S_i}^{S_i+W_i} d_{mi} I_y(y)\sin(\alpha_n y)\,dy \quad (3)$$

$$\text{where} \quad I_y(y) = \frac{\sin\left[2n\pi\frac{(y-y_i)}{wi}\right]}{\sqrt{1-\left[\frac{2(y-y_i)}{wi}\right]^2}} \qquad \text{where} \quad I_z(y) = \frac{\cos\left[2(n-1)\pi\frac{(y-y_i)}{wi}\right]}{\sqrt{1-\left[\frac{2(y-y_i)}{wi}\right]^2}}$$

where w_i being the width of the ith strip, y_i is the distance from origin to the center of strip, m and k vary from 1 to total number of basis functions defined in computation

The Current Eigenvector Matrix And Characteristic Impedances

The normalized current eigenvector matrix $[M_I]$ and the characteristic impedances of the multiple coupled structures are also computed by using the solutions for the currents and the field's distribution associated with each mode [1].

An equivalent voltage vector matrix can also be defined by utilizing the orthogonality between the current and the voltage eigenvectors and is given by

$$[M_V] = \left[[M_I]^T\right]^{-1} \tag{4}$$

Mode characteristics impedance of the coupled microstrip lines are evaluated for all hybrid modes in a straightforward manner by calculating the power associated with a given line for a given mode and the corresponding line current as shown in [1].The line mode impedance is given by

$$Z_{lm} = \frac{power\ \ associated\ \ with\ \ line\ \ l\ \ for\ \ \text{mode}\ \ m\ \ (P_{lm})}{\left(normalized\ \ current\ \ l\ \ for\ \ \text{mode}\ \ m(I_{lm})\right)^2} \tag{5}$$

e.g. The three-coupled line structure supports three dominant modes as OE, OO and EE which correspond to odd-even (mode a), odd-odd (mode b) and even-even (mode c) mode . Each mode has its own modal phase constant, Eigenvoltage vector, and characteristic impedance.

Attenuation

To evaluate attenuation due to dielectric and conductor losses, following methods are used.

***Dielectric losses*:** perturbation theory is used, based on 1.) The loss tangent being sufficiently small, and 2.) Fields for the lossless condition, which are first computed, being used as the perturbed fields. To find a expression for α_d, Maxwell's equation are written for both lossy and lossless conditions, and then by applying green's theorem to the integrals the following formula is obtained:

$$\alpha_d = \frac{\sum_i \omega\varepsilon_i \tan\delta_i \iint\left[|E_x|^2 + |E_y|^2 + |E_z|^2\right]dS}{2\,\text{Re}\iint\left[E\times H^*\right]dS} \tag{6}$$

where the subscript i represents the ith dielectric layer having dielectric constant ε_i and loss tangent $\tan\delta_i$.

Conductor losses: Attenuation due to the imperfect conductor is obtained via conventional perturbation formula,

$$\alpha_c = \frac{R_S \int_C |H_t|^2 dl}{2\,\mathrm{Re} \iint \left[E \times H^* \right] dS} \tag{7}$$

where R_s is the surface resistance, H_t is the tangential magnetic field on the conducting surface. Conventional method neglects the metal conductor thickness but in this paper the conductor thickness has been considered as in [7], where the contour integral can be written as

$$\int_C |H_t|^2 dl = \int_{a_i}^{b_i} |H_t(x=0)|^2\, dy + \int_{a_i}^{b_i} |H_t(x=t)|^2\, dy + \int_o^t |H_t(y=s_i)|^2\, dx + \int_o^t |H_t(y=s_i+w_i)|^2\, dx \tag{8}$$

Above equation is used to calculate the conductor loss at all four walls of ith metal strip.

NUMERICAL RESULTS

Computer program has been developed to evaluate all the normal mode parameters of general three microstrip lines in shielded suspended substrate (SSS) and inverted microstrip lines. Fig. 2 shows the dispersion characteristics of symmetric three coupled lines in suspended substrates structure. Fig. 2(a) represents the effective dielectric constant and Fig. 2(b) and (c) show the mode current ratios and characteristic impedances for all three different modes. Fig. 2(d) represents the Conductor and Dielectric losses for three symmetric coupled microstrip lines in suspended substrate. It should be noted that in suspended case the even-even mode effective dielectric constant is lowest and in odd-even mode dielectric constant is highest. Attenuation for three-coupled microstrip line has also been investigated. In this calculation the tangential magnetic fields has been calculated considering zero thickness of metal conductor and then by using the perturbation formula, the conductor loss has been calculated for finite thickness of metal conductor. Loss has been calculated for all the four walls of metal conductor using the equation discussed in (8).

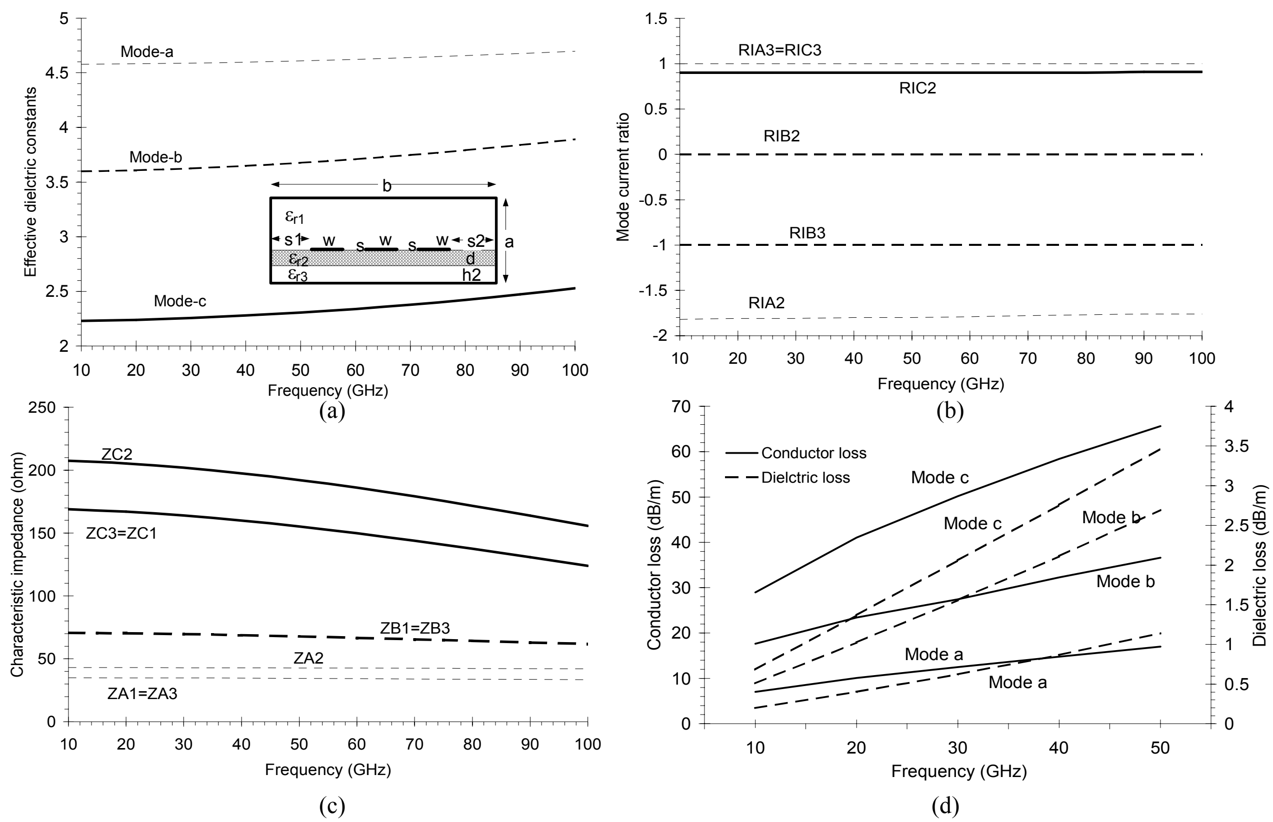

Fig. 2: (a) Effective dielectric constant (b) Mode current ratio (c) Characteristic Impedance (d) Conductor and Dielectric losses for three symmetric coupled microstrip lines in shielded suspended substrate structure. (w=0.1 mm, s=0.05 mm, d=0.1 mm h2=0.1 mm, s1=s2, b=2.30 mm, a=20.1 mm, $\varepsilon_{r1}=\varepsilon_{r3}=1.0$, $\varepsilon_{r2}=8.875$, tanδ=. 0004, $\sigma = 4.1 \times 10^7$ S/m, t=5μm).

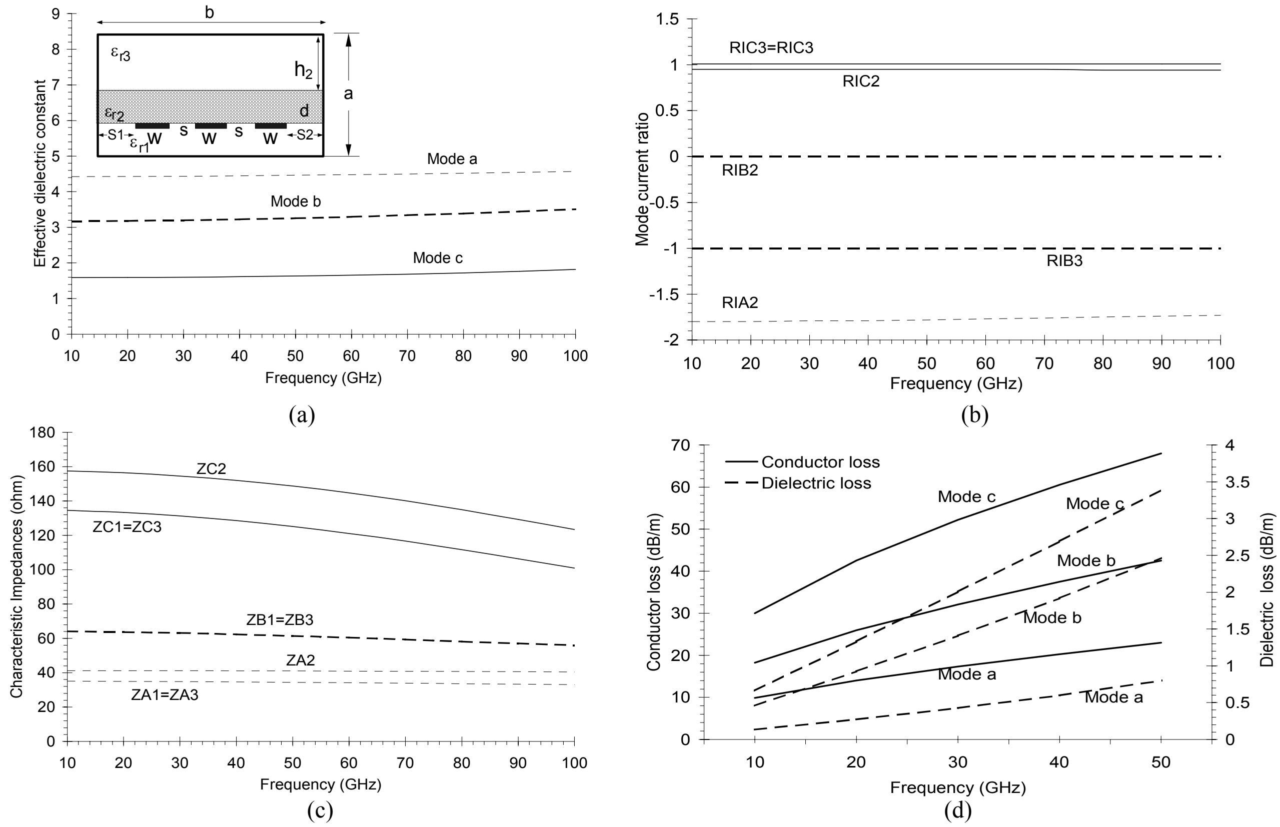

Fig. 3: (a) Effective dielectric constant (b) Mode current ratio (c) Characteristic Impedance (d) Conductor and Dielectric losses for three Inverted microstrip lines (w=0.1 mm, s=0.05 mm, d=0.1 mm h2=19 mm, s1=s2, b=2.40 mm, a=19.2 mm, $\varepsilon_{r1}=\varepsilon_{r3}=1.0$, $\varepsilon_{r2}=8.875$, $\tan\delta=.0004$, $\sigma = 4.1 \times 10^7$ S/m, t==5μm).

Normal mode parameters for inverted three-coupled microstrip lines are presented in Fig. 3. The variation of effective dielectric constant with frequency has been computed and depicted in Fig. 3(a). Mode current ratios and mode characteristic impedances are depicted in Fig. 3(b) and (c). The inverted microstrip lines are as advantageous as suspended microstrip where the larger strip dimensions can be achieved as compare to conventional microstrip lines. Fig. 2(d) shows the Conductor and Dielectric losses for three inverted microstrip lines.

CONCLUSION

All the normal mode parameters for three symmetric coupled microstrip lines in suspended substrate case and inverted three microstrip lines has been presented with full wave modal analysis. Numerical results include the propagations constant including conductor and dielectric losses, modal characteristic impedances, and the equivalent current eigenvector matrices of multiple coupled lines. The results for all the frequency dependant propagation characteristics are very useful for the design of microwave and millimeter wave circuits for wideband applications.

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