Analysis of Stitch Line for Monolithic Microwave Integrated Circuits

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ABSTRACT

A new type of transmission line, called the stitch line, is introduced for possible applications in monolithic microwave integrated circuits. A simple approximate analysis method under the assumption of a quasi-TEM propagation is presented which includes the conductor loss. The s-parameters of a two-port circuit constructed with these stitch lines are computed based on the analysis. The results agree well with measured characterizations.

1. INTRODUCTION

As shown in Fig.1, the stitch line is essentially a broadside coupled microstrip line. It consists of the long air bridge section (A) and the stitch-like section (B) which mechanically support section A. This configuration is amenable to the monolithic integration process. The lower conductor forms a microstrip on a GaAs substrate and is covered with a passivation layer. The upper conductor in the air bridge section is floating in air while it lands on the passivation layer at the stitch section. Because of the broadside coupling configuration, the stitch lines can be used for building couplers, baluns and filters.

Some of the advantageous features of the stitch line are as follows.

(1) Because of the air bridge section, high impedance lines can be built on a high permittivity substrate as GaAs.
(2) The attenuation of the odd-like mode (where the field is mainly between the upper and lower strips) is reduced due to the existence of air.
(3) For broadside coupled-line structures, any length of tight coupling section can be built.

2. ANALYSIS

In this simplified analysis, no electromagnetic characterizations of the discontinuity between sections A and B are included. We treat the problem as a cascaded three-wire quasi-TEM transmission line with lossy conductors. Four-port S parameters of each section are found which are cascaded subsequently. The analysis proceeds in the following manner. First, the capacitance matrix per unit length is calculated for each section by means of the spectral domain method [1,2,3]. From the hypothetical air-filled configuration, the inductance matrix is obtained. Next, the conductor loss is introduced by means of the phenomenological loss equivalence method [4] which modifies the inductance matrix. Finally, from the inductance and capacitance matrices, the propagation constants and the characteristic impedances of the c- and π-modes are obtained [5,6].

2.1 Capacitance matrix

The transverse cross section for analysis is shown in Fig.2. The two conductors are assumed to be infinitely thin perfect electric conductors. Under the quasi-TEM assumption, the capacitance matrix of each section can be derived by the spectral domain method. Since this method is well known, the details are omitted. Essentially, the following algebraic equation is solved for unknown charge distributions on the two conductors for a given combination of the conductor potentials.

$$\begin{bmatrix} \tilde{\Phi}^{(1)} \\ \tilde{\Phi}^{(2)} \end{bmatrix} = \frac{1}{\varepsilon_o} \begin{bmatrix} \tilde{G}_{11} & \tilde{G}_{12} \\ \tilde{G}_{21} & \tilde{G}_{22} \end{bmatrix} \begin{bmatrix} \tilde{\rho}^{(1)} \\ \tilde{\rho}^{(2)} \end{bmatrix} \tag{1}$$

where $\Phi^{(i)}$ is the Fourier transform of the potential of the i-th conductor (i = 1, 2) with respect to the ground plane, $\rho^{(i)}$ is the Fourier transform of the charge distribution on the i-th conductor, and G_{ij} is the Fourier transformed Green's function matrix element. For the appropriate choice of the excitation potential combination, one can find by solving the above equation the capacitance matrix with its elements C_H, C_L and C_M as defined in Fig.3a. The dielectric constants of the filling materials are considered as complex quantities so that the dielectric losses are taken into account under the quasi-TEM approximation.

2.2 Inductance matrix and conductor loss

It is well known that, under the quasi-TEM approximation containing the non-magnetic materials, the inductance matrix can be derived from the capacitance matrix of the hypothetical transmission line with the dimensions identical to the original one with all the dielectric materials removed since the latter becomes a TEM line [1]. To this end, we first calculate the capacitance matrix consisting of C_{0H}, C_{0L} and C_{0M} shown in Fig.3b by the spectral domain method described above. The inductance matrix can be readily derived. However, as a preparation for introducing the conductor loss, we will modify the procedure in the

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following way.

The conductor loss is mainly caused from the current distributions in the upper (w_1) and lower (w_2) conductors. With respect to the lower conductor as a reference, the inductance matrix can be written as

$$\begin{bmatrix} L_{01} & L_{0m} \\ L_{0m} & L_{02} \end{bmatrix} = \varepsilon_o \mu_o \begin{bmatrix} C_{0M} + C_{0H} & -C_{0H} \\ -C_{0H} & C_{0L} + C_{0H} \end{bmatrix}^{-1} \qquad (2)$$

where L_{01} is the inductance in the "line" formed by the upper and lower conductors, L_{02} the one by the lower conductor and the ground while L_{0m} by the upper conductor and the ground. This choice expedites the conductor loss calculation as shown shortly.

Up to now the conductors are assumed to be infinitely thin perfect electric conductors. Therefore, these inductances are considered as the external inductances. To approximate the losses due to the conductors, we must consider the conductor thickness so that the field penetration is taken into account. In most practical cases, $w_1 \approx w_2$, $d_2 + d_3 << d_4$ and $t_1 \approx t_2$. Therefore, the effect of the ground plane on the conductor loss will be neglected and the conductor losses will be approximated by the loss related to L_{01}. Although these approximations have no rigorous justification, they are justified in many practical results reported shortly. Under these approximations and with $w_1 = w_2$ and $t_1 = t_2$, the loss calculation is conducted with the use of the structure shown in Fig.4a. Because of the symmetry, the conductor loss and the internal inductance are expressed by those of the microstrip line in Fig.4b. The conductor loss per unit length (R) and the internal inductance per unit length (L_{int}) of the microstrip line in Fig.4b are now computed by the phenomenological loss equivalence (PEM) method [4]. The obtained R and L_{int} are combined with the external inductance L_{01} in (2) and total "inductance" is written as L'_{01} as follows.

$$L'_{01} = L_{01} + \left(2 \cdot L_{int} + j \cdot \frac{2 \cdot R}{2 \cdot \pi \cdot freq} \right) \qquad (3)$$

At this stage, we go back to the previous system of the ground plane as the reference. The inductance matrix under the quasi-TEM approximation is now given by

$$\begin{bmatrix} L'_H & L'_M \\ L'_M & L'_L \end{bmatrix} = \frac{D_1}{D_2} \begin{bmatrix} L'_{01} + L_{02} - 2L_{0m} & L_{0m} - L_{02} \\ L_{0m} - L_{02} & L_{02} \end{bmatrix} \qquad (4)$$

where

$$D_1 = \begin{vmatrix} L'_{01} & L_{0m} \\ L_{0m} & L_{02} \end{vmatrix}$$

$$D_2 = \begin{vmatrix} L_{02} & L_{02} - L_{0m} \\ L_{02} - L_{0m} & L'_{01} + L_{02} - 2L_{0m} \end{vmatrix}$$

From these inductances (L'_H, L'_L, L'_M) and the capacitances (C_H, C_L, C_M), the characteristic impedances and the propagation constants of the c- and π-modes can be otained [5,6]. It is a straightforward manner to find the 4-port S-parameters for each section [7]. Finally, these S-parameters of as many sections as the circuit contains are cascaded to obtain the circuit performance.

3. RESULTS AND DISCUSSIONS

The circuit tested is shown in Fig.5. This circuit is built on a GaAs substrate. The dielectric between the upper and lower conductors is SiN. The conductors are made of gold (R_s = 0.23 x 10^{-5} ohm-m). In Fig.5, the ports 'a,b,c,d' and 'e,f,g,h' form stitch lines. The stitch lines 'a,b,c,d' and 'e,f,g,h' are identical in this test circuit. The ports 'a', 'c' and 'g' are terminated by 50 ohms. The ports 'b', 'e' and 'f' are grounded while 'd' and 'h' are connected. This circuit was built and measured by Hughes Aircraft.

In the circuit analysis and measurement, the port 'a' is considered as the input port (port 1) while the port 'c' is considered as the output port (port 2). The measured and computed results are shown in Fig.6. Even though this circuit contains 32 stitch discontinuities, the computed results are in good agreement with the measured data.

4. CONCLUSIONS

A new transmission line called the stitch line was introduced for monolithic microwave integrated circuits. A simple method for analysis was developed. In this method, the spectral domain method is used for derivation of the distributed capacitances and inductances. The equivalent microstrip line model was used for approximating the conductor losses and the internal inductances. A stitch line circuit was built and tested. The experimental results are compared with the results calculated by this method. Even though the electromagnetic characterizations of the discontinuities are not included, the computed results are in good agreement with the measured results. The method presented in this paper is shown to be effective to analyze this circuit configuration.

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REFERENCES

[1] E. Yamashita, "Variational method for the analysis of microstrip-like transmmission lines," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-16, pp. 251 -256, Aug. 1968.

[2] T. Itoh, *Numerical Techniques for Microwave and Millimeter-Wave Passive Structures.*, chapter 5, John Wiley & Sons, NY.

[3] T. Kitazawa and Y. Hayashi, "Analysis of Unsymmetrical Broadside-Coupled Striplines with Anisotropic Substrates" *IEEE Trans. Microwave Theory Tech.*, vol..MTT-34, pp. 188 - 191, Jan. 1986.

[4] H,-Y Lee and T. Itoh, "Phenomelogical loss equivalence method for planar quasi-TEM transmission line with a normal conductor or superconductor," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-37, pp. 1904 - 1909, Dec. 1989.

[5] V. K. Tripathi, "Assymetric coupled transmission lines in an inhomogeneous medium," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp.734 - 739, Sept. 1975.

[6] V. K. Tripathi and C.L.Chang,"Quasi-TEM parameters of nonsymmetrical coupled microstrip lines,", *Int. J. Electron.*, vol. 45, no. 2, pp.215 -223, 1978.

[7] G. Gonzalez, *Microwave Transistor Amplifiers*, sec. 1.8, Prentice-Hall, New Jersey.

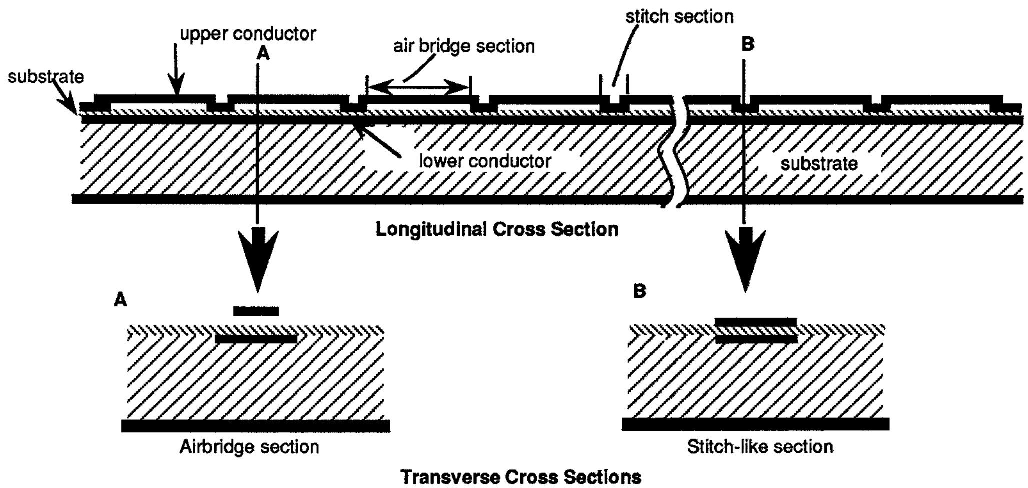


Fig. 1 The structure of Stitch Line

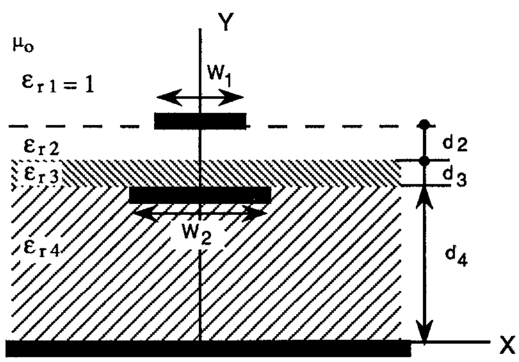


Fig. 2 Geometry of the coupled line for the spectral domain method (Thickness of the conductors are assumed to be zero.)

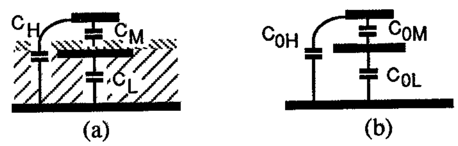
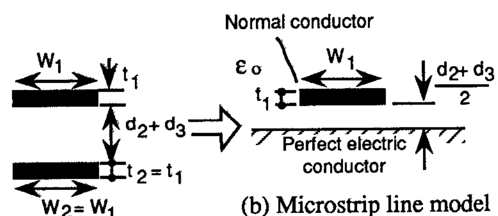


Fig. 3 (a) Capacitances with substrates (b)without substrates



(a) The coupled line approximation

(b) Microstrip line model (the upper half of (a))

Fig. 4 Microstrip line model to approximate the conductor loss

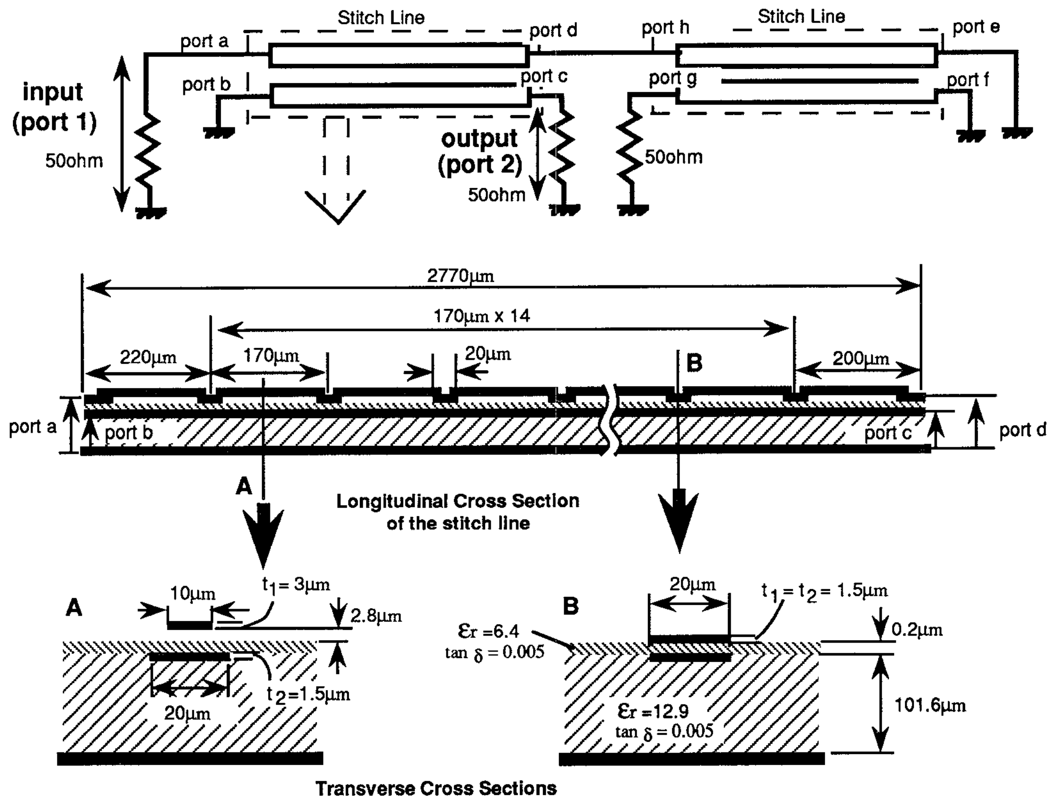


Fig. 5 The measured circuit

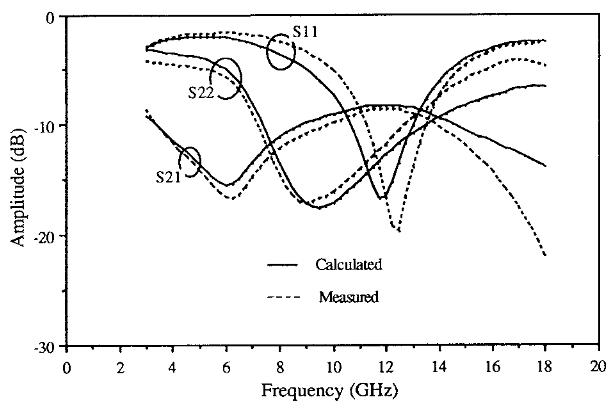


Fig. 6 The measured and calculated results