Low-Distortion and Low-Crosstalk Characteristics of Picosecond Pulses in a Dual-Plane Coupled Microstrip Lines Structure

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***Abstract*— Investigation of the propagation and crosstalk of ultrashort electrical pulses in a dual-plane coupled microstrip lines structure is reported. The current distributions and propagation constants of the dominant c- and π- modes are calculated by using the spectral domain method, and the full-wave analysis results obtained are incorporated into a FFT algorithm to study pulse distortion and crosstalk in the transmission lines. Computer simulation results reveal the superior low-distortion, low-crosstalk characteristics of this transmission line structure, which can be used as interconnects in high-density, high-speed integrated circuits.**

I. Introduction

The problem of crosstalk and coupling between interconnects in ULSI and MMIC's has been a topic of intensive study during the past few years, due to its crucial importance in designing these extremely high-speed circuits [1]–[3]. While smaller interline spacings are required to realize increased integration densities, signal coupling becomes very strong, which may cause reliability problems and even damage to circuit performances.

Several authors have reported their efforts in reducing the crosstalk in high-speed interconnects. Zhang *et al.* [3] have presented design optimization of VLSI interconnects modeled by distributed coupled transmission line networks. When ultrashort pulses with picosecond durations are employed to realize increased circuit speeds, full-wave analysis becomes necessary for accurate characterization of pulse behaviors in the interconnection lines. By using the spectral domain approach [4], Carin and Webb [5] have studied pulse isolation effects by introducing grounded isolation lines, and Gilb and Balanis [6] have reported significant reduction in pulse crosstalk through the use of substrate compensation.

In this letter, we study the pulse distortion and crosstalk in a dual-plane coupled microstrip lines structure. The frequency dispersion of this structure has been analyzed by Fukuoka *et al.* [7]. To predict the propagation of ultrashort pulses in this asymmetric structure, however, detailed current distributions as well as propagation constants of the dominant modes must be calculated. By combining the full-wave analysis results into a FFT algorithm, we are able to simulate pulse distortion on the signal line and crosstalk to the adjacent line. Compared with conventional, single-plane couple microstip lines, the dual-plane structure causes much less distortion to the signal pulse and crosstalk to the adjacent line, mainly because of the unique current distributions on the strip lines in different layers. With recent progress in multilayer MMIC technology [8], this kind of transmission line structure can be easily fabricated, and should make itself a very promising candidate for interconnects in high-density, high-speed integrated circuits.

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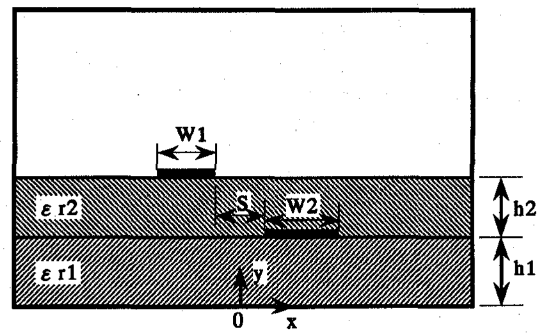

Fig. 1. Cross-sectional view and geometries of the dual-plane coupled microstrip lines structure.

II. Numerical Analysis

Fig. 1 shows the cross-sectional view of the dual-plane coupled microstrip line structure under investigation. The two strip conductors are assumed to be negligibly thin and perfectly conducting, and the dielectric substrate is lossless and isotropic. The dominant propagation modes in this structure are the c- and π- modes, whose current densities are in-phase and out-of-phase, respectively [6]. This transmission line structure can be readily analyzed by using the spectral domain method, and the frequency-dependent propagation constants have been calculated by Fukuoka *et al.* [7]. In order to predict pulse propagation in the time-domain, one must know the current amplitudes on the strip lines in addition to the phase velocities. The current densities (eigen-vectors) on each strip are determined first, and are then integrated over the strip width to give the current amplitudes on the conductors. Fig. 2 shows some numerical results of the ratio of current amplitudes, I_{1z}/I_{2z}, for the c- and π- mode, respectively. It is found that for this asymmetric coupled lines structure, the current amplitudes on the two lines are quite different from each other. Neither is the current ratios, I_{1z}/I_{2z}, constant for

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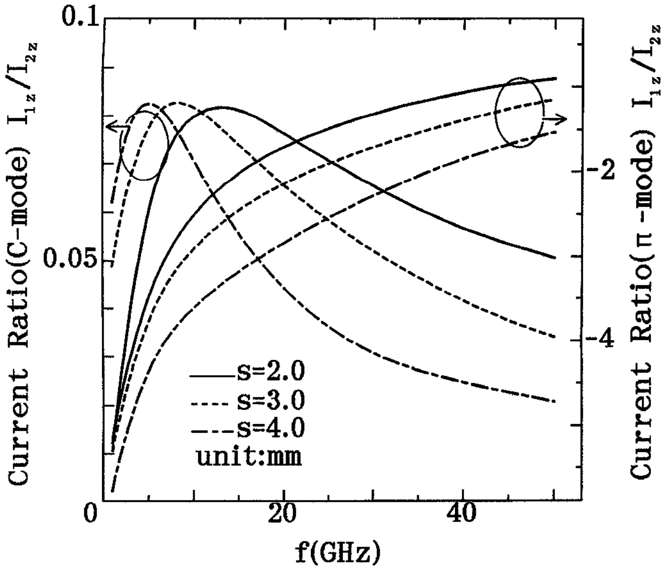

Fig. 2. Frequency-dependent ratio of the longitudinal currents on the two strips in a dual-plane coupled lines structure. (Other parameters: $w_1 = w_2 + 1.2$ mm, $h_1 = h_2 = 1.27$ mm, $\epsilon_{\pi 1} = \epsilon_{\pi 2} = 10.5$.)

different frequencies. Note also that the current ratios for the π-mode are of negative values, which reveals the out-of-phase characteristics of this propagation mode.

III. Simulation Results

The procedure of computer simulations is similar to that described in our recent paper [9]. The ratios of current amplitudes shown in Fig. 2, $I_{1z}/I2z$, are defined to be $a_2c(\omega)$ and $a_2\pi(\omega)$, for the c- and π-modes, respectively. The linear combination of the two modes, which gives a unit amplitude signal on the signal line and no signal on the coupling line, is expressed by the following matrix:

$$[C(\omega)] = \begin{bmatrix} c_{c1} & c_{c2} \\ c_{\pi 1} & c_{\pi 2} \end{bmatrix}, \tag{1}$$

where $c_{jk}(j = c, \pi; k = 1, 2)$ is the constant of the linear combination for the jth mode when the kth conductor is excited. Finally, the pulse response after a propagation distance of L is obtained as follows:

$$v_1(L,t) = \mathcal{F}^{-1}\Big\{c_{c1}(\omega)\tilde{V}(\omega)e^{-\beta_c(\omega)L} + c_{\pi 1}(\omega)e^{-\beta_\pi(\omega)L}\Big\} \tag{2}$$

$$v_2(L,t) = \mathcal{F}^{-1}\Big\{a_{2c}(\omega)c_{c1}(\omega)\tilde{V}(\omega)e^{-\beta_c(\omega)L} + a_{2\pi}(\omega)c_{\pi 1}(\omega)\tilde{V}(\omega)e^{-\beta_\pi(\omega)L}\Big\}, \tag{3}$$

where$\beta_i(\omega)(i = c, \pi)$ is the propagation constant for the c- and π- mode, respectively.

Fig. 3 shows computer simulation results of the propagation as well as crosstalk of a Gaussian pulse in two different types of coupled microstrip lines structures. The FWHM (full width half maximum) of the pulse is 40 ps. Fig. 3(a) is the result for the case of single-plane coupled microstrip lines [9].

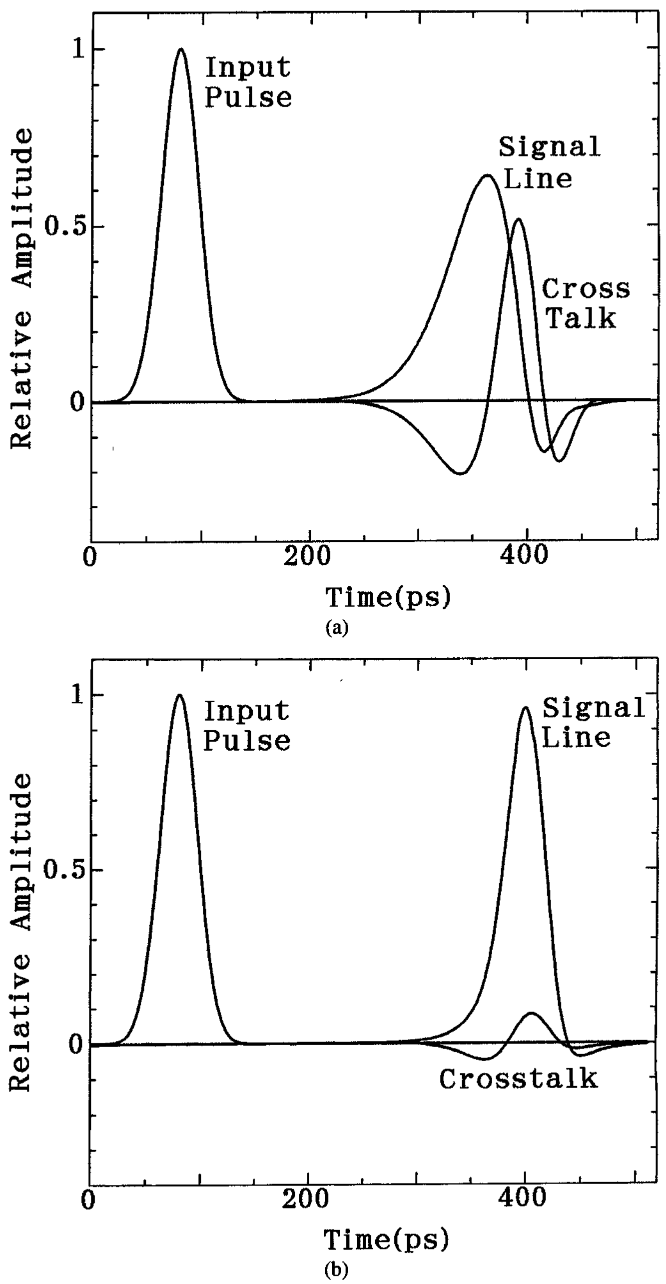

Fig. 3. Comparison of computer simulation results of the distoration and crosstalk of a 40-ps Gaussian pulse along (a) single-plane coupled microstrip lines and (b) dual-plane coupled microstrip lines.

The line parameters are: $w_1 = w_2 = 1.2$ mm, $s = 2$ mm, $h_1 = 2.54$ mm, $h_2 = 0, \varepsilon_{r1} = \varepsilon_{r2} = 10.5$. Both distortion and crosstalk are significant. After 30-mm propagation along the transmission lines, the 40-ps input Gaussian pulse is broadened to 85 ps in FWHM, with its peak amplitude fallen to 64% that of the input pulse. Meanwhile, the crosstalk pulse has also reached a significant amplitude, approximately 52% that of the original signal pulse.

Fig. 3(b) shows the propagation of the same input pulse along the dual-plane coupled lines structure analyzed in the previous section $w_1 = w_2 = 1.2$ mm, $s = 2$ mm, $h_1 = h_2 = 1.27$ mm, $, \varepsilon_{r1} = \varepsilon_{r2} = 10.5$. As can be seen, there is very little distortion in the waveform of the signal pulse, with its FWHM slightly increased from 40 ps to 43 ps. The pulse crosstalk is also very weak, with its peak amplitude only 8.6% that of the input pulse. This is approximately 6 times smaller than that of the coplanar microstrip lines in Fig. 3(a). The superior low-distortion, low-coupling effect of the dual-plane coupled lines structure is mainly due to the unique current distributions on the strip conductors. Detailed discussions on the mechanism of coupling in this structure and experimental results will be presented in a future report.

IV. Conclusion

The propagation and crosstalk of picosecond pulses in a dual-plane coupled microstrip lines structure has been investigated. Due to the unique current distributions, this transmission line structure presents extremely low-distortion, low-crosstalk characteristics compared with conventional, single-plane coupled microstrip lines. Computer simulation results of pulse propagation along the proposed transmission lines have been presented, and compared with the case of conventional coupled microstrip lines. The superior low-coupling properties of this transmission line structure should make it an important candidate for interconnects in high-density, high-speed integrated circuits.

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