Characterization of A Dual-Plane Microstrip Interconnect with Reduced Pulse Distortion and Crosstalk

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ABSTRACT

Interconnects with low signal distortion and crosstalk are important for high-density, high-speed integrated circuits. In this paper we describe a dual-plane, multi-conductor interconnect which exhibits superior propagation characteristics over conventional coplanar structures. Distortion and crosstalk of picosecond pulses in a four-line structure are investigated by combining the full-wave spectral domain method with an FFT algorithm. For the special case of four coplanar microstrips, we obtain identical results with those in the literature. Meanwhile, for the newly proposed dual-plane structure, our simulation shows only slight distortion in the signal pulse, and a substantial reduction in crosstalk to the neighboring lines.

INTRODUCTION

The pursuit of low signal distortion and crosstalk interconnects is an important issue in designing high-density, high-speed integrated circuits[1]. While smaller interline spacings are required to realize increased packaging densities, signal coupling and distortion become significant, which may cause reliability problems and even damage to circuit performances. Several types of interconnects with improved pulse propagation characteristics have been proposed recently, and characterized with a full-wave analysis approach. Carin and Webb[2] studied the pulse isolation effect of a grounded line inserted between two signal lines, and Balanis and Gilb[1] reported significant reduction in pulse distortion and crosstalk through the use of substrate compensation.

Since increasing interline spacings in a coplanar, multi-conductor interconnect is not an effective way of reducing pulse distortion and crosstalk[3], as will also be shown in this paper, we consider here a modified structure which introduces a vertical offset between two

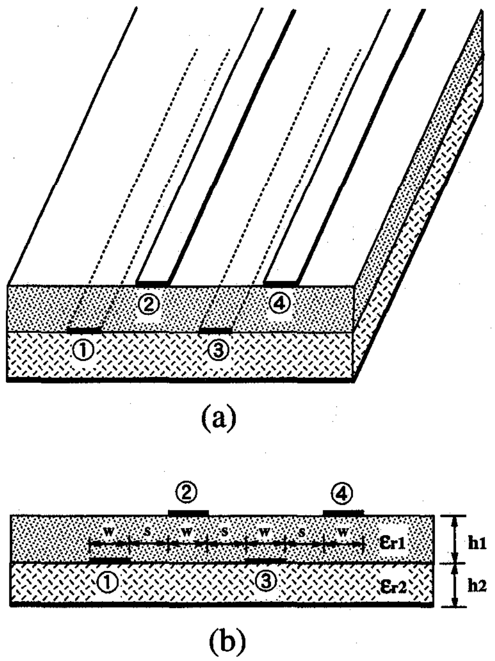

Fig. 1. (a) Three-dimensional and (b) Cross-sectional view of a dual-plane, multi-conductor microstrip interconnect.

neighboring lines. A two-line structure with such an offset was first analyzed by Fukuoka *et al* [4], where the frequency-dependent phase velocities and characteristics impedances of the even and odd modes were calculated. In a recent paper[5], we reported some simulation results of the propagation of picosecond pulses in such a two-line structure, which revealed a significant reduction in pulse distortion and crosstalk compared with the case of coplanar coupled lines. Encouraged by these initial results, we have made further investigation into this dual-plane structure, and this paper reports for the first time a detailed description of time-domain propagation characteristics of a general dual-plane, multi-line interconnect.

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ANALYSIS METHOD

Fig. 1 shows the configuration of the dual-plane, multi-line interconnect under investigation. For simplicity identical microstrip width, w, and horizontal line spacing, s, have been considered in this work. The strip conductors are assumed to be negligibly thin and perfectly conducting, and the dielectric substrate is lossless and isotropic. It is obvious that the conventional coplanar microstrip interconnect is a special case of this structure, which can be realized by simply making h_1=0.

For a n-line structure there exist n dominant propagation modes, whose phase velocities and current distributions can be obtained by using the well-known spectral domain method[6]. Fig. 2 plots the normalized phase velocities, β/β_0, of the four propagation modes in a dual-plane, four-line structure with the following parameters:$w=s=0.5$mm,$h_1=h_2=0.3175$mm,$\varepsilon_{r1}=\varepsilon_{r2}=2.2$. Th difference in phase velocities for different modes(intra-modal dispersion), and the frequency-dependent characteristics of each mode(inter-modal dispersion) are two main factors responsible for pulse distortion and crosstalk in this multi-line interconnect.

To predict pulse propagation in the time-domain, we must also know the current amplitude of each mode on each line, which can be determined by integrating the calculated current densities across the strip width. After these current amplitudes are obtained, an FFT algorithm can be readily applied for computer simulation of pulse propagation along the interconnect. The simulation procedure is similar to that for a two-line structure, which has been described in detail in our previous paper[7].

SIMULATION RESULTS

Fig. 3 shows our simulation results of pulse propagation in a coplanar, four-microstrip interconnect, which has been studied previously by Gilb and Balanis[8]. Identical parameters were chosen first to offer a comparison of simulation results. A Gaussian input pulse with FWHM(Full Width at Half Maximum) τ=20ps and unit amplitude is excited on line 1. Simulation results of signals on the four lines after a propagation distance of L=100mm are plotted in Fig. 3(a), which agree perfectly with those in Fig. 5 of Ref. [8]. The 20ps input Gaussian pulse on line 1 has been broadened to be 34ps in FWHM, with the peak amplitude about 57 percent that of the original pulse. Meanwhile, the crosstalk pulses on the other three lines are also quite significant, with the peak amplitude on line

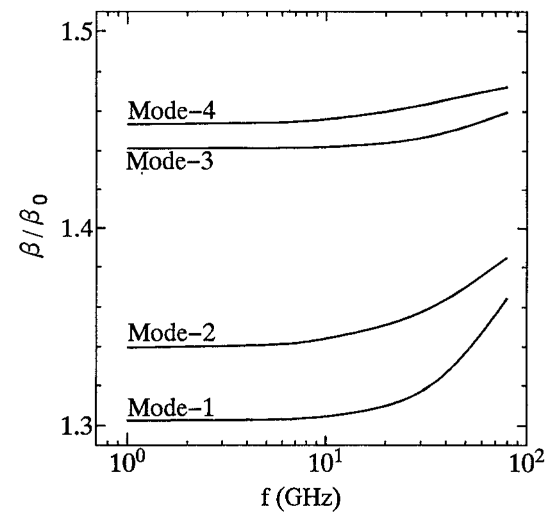

Fig. 2. Spectral domain analysis results of the frequency-dependent phase velocities of the four dominant propagation modes in a dual-plane, four-line structure.

2 approximately 33 percent that of the original Gaussian pulse.

To investigate how the line separation will affect pulse distortion and crosstalk, we double the line spacing to s =1.0mm, and make another simulation with other parameters remained identical. The results are plotted in Fig. 3(b). As can be seen, no significant improvement in either pulse distortion or crosstalk is achieved when the line spacing s is increased from 0.5mm to 1.0mm. This is mainly due to the very slow change in intra-modal dispersion(difference in phase velocities for different modes) with increasing line spacings. Similar results have also been reported by Djordjevic, Sarkar and Harrington[3].

Since increasing the horizontal interline separation is not effective in reducing pulse distortion and crosstalk, we investigate a dual-plane structure where two adjacent lines are vertically offset by half the substrate height. Fig. 4 shows our simulation results for a dual-plane, four-line structure with identical parameters with those in Fig. 3 except for the vertical offset of lines 1 and 3. For both cases of s =0.5mm and 1.0mm, a substantial reduction in the distortion of signal pulse on line 1 and crosstalk to the other three lines has been observed. In Fig. 4(a), the FWHM of the signal pulse on line 1 increased very little(from 20ps to 22ps) after 100mm propagation, and its peak amplitude is 93 percent that of the input pulse. The maximum amplitude of the crosstalk signal, which appears on line 3 for the present structure,

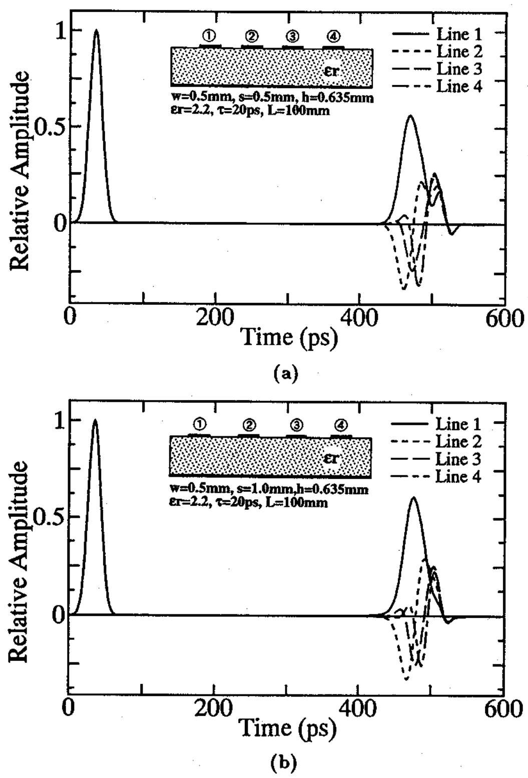

Fig. 3. Simulation results of pulse distortion and crosstalk in a coplanar, four-line interconnect with different line spacings: (a) s=0.5 mm and (b) s=1.0 mm.

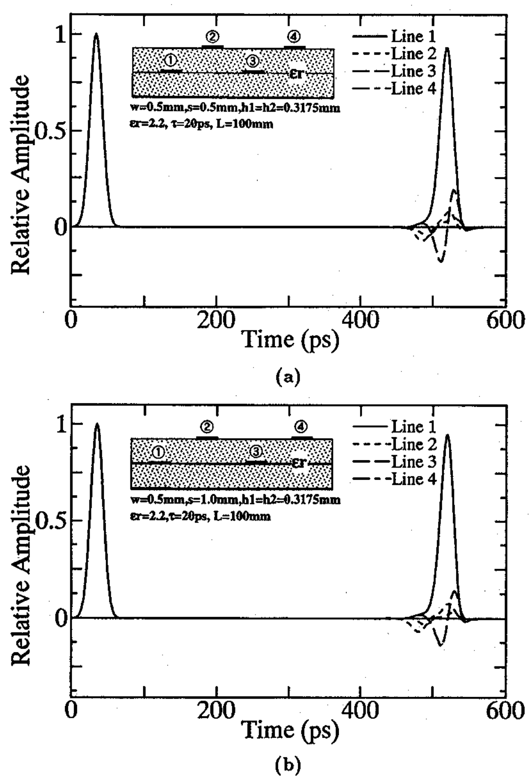

Fig. 4. Simulation results of pulse distortion and crosstalk in a dual-plane, four-line interconnect with different line spacings: (a) s=0.5 mm and (b) s=1.0 mm.

is 17 percent that of the original pulse. This is approximately half that of the crosstalk amplitude for the corresponding coplanar structure in Fig. 3(a). On the other hand, increasing the horizontal interline spacing, s, shows only slight improvement in both pulse distortion and crosstalk, similar to the results for the coplanar structure described in Fig. 3.

CONCLUSION

In this paper we have investigated a dual-plane, multi-line microstrip interconnect which exhibits improved propagation characteristics for ultrashort pulses. Our simulation results show that introducing a vertical offset between neighboring microstrips is much more effective in reducing pulse distortion and crosstalk than just increasing the horizontal interline spacings in a conventional coplanar structure. The superior low distortion and crosstalk properties of this novel waveguide structure should make it a promising candidate for interconnects in future high-density, high-speed integrated circuits.

ACKNOWLEGDMENT

The authors thank the Casio Science Promotion Foundation for financial support to the present work.

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