A New Via Fence Structure for Crosstalk Reduction in High Density Stripline Packages

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Abstract — **Via fences are often placed between stripline conductors to suppress unwanted parallel plate mode coupling. However, if the striplines are too close to a fence, the coupling between the striplines is enhanced rather than reduced. In this paper we analyze the coupling between two striplines separated by a via fence using electromagnetic simulation for various dimensional parameters. Finally, we introduce a new via structure that significantly reduces the unwanted coupling.**

I. INTRODUCTION

Advancements in substrate technology have led to the development of multi-layer packages achieving higher packaging densities for microwave integrated circuits. In multi-layer packages microwave signals can be routed on different layers buried within the package. Connections between these layers may be made with metal vias or plated holes. The microwave signals are typically guided with shielded "stripline" type transmission lines, a center strip located between two ground planes.

One advantage of a stripline structure is that the ground planes provide shielding of the signal line from circuitry outside of the ground planes. Thus two or more stripline structures can be stacked one on top of another in a multi-layer fashion with each stripline structure electrically isolated from the other. If, however, two or more stripline circuits are located between the *same* two ground planes, unwanted coupling of the RF signals may occur between them. This undesired coupling of signals is usually referred to as "crosstalk". For many stripline packages the control of crosstalk becomes the major design issue.

II. STRIPLINE COUPLING MODES

There are generally two types of coupling between stripline structures, proximity coupling and parasitic coupling. Proximity coupling occurs when two parallel striplines are in close proximity and have some form of electromagnetic coupling between them. This type of coupling is usually predictable and sometimes desirable, as in the case where two coupled lines are used as a directional coupler.

Parasitic coupling usually occurs as a result of parallel plate mode propagation. Parallel plate modes are easily excited when a potential difference is developed across the stripline ground planes, ideally held at the same potential. This potential difference may be developed by a circuit discontinuity or because of an asymmetry in the structure such as in the case of a vertical stripline to stripline interconnect. Parallel plate waveguide modes easily propagate in the package and may couple energy between two or more stripline structures that may be far enough apart to be normally uncoupled. These modes are undesired and usually difficult to predict.

A common solution is to place via fences between each of the stripline structures to reduce the electrical couplings between them [1-2]. These fences are typically a row of closely spaced metal vias that connect the top and bottom stripline ground planes for the purpose of suppressing parallel plate waveguide mode propagation. Although this technique generally works well for striplines that are not in close proximity, it does not work well for striplines that are close to each other. When a via fence is placed between two *closely* spaced parallel striplines, a new coupling mode is introduced that increases the coupling rather than reducing it [3].

III. ANALYSIS OF STRIPLINE COUPLING

In many high-density stripline packages, layout issues force two (or more) striplines to be routed adjacent to one another in very close proximity, which results in electromagnetic coupling between the two conductors. The nature of this coupling is illustrated in Fig. 1.

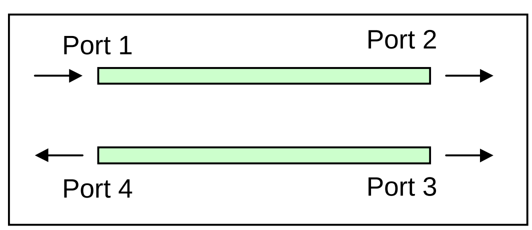

Fig. 1 - Coupling Circuit I/O Model

A signal applied to one conductor at port 1 is transmitted primarily to port 2 with some of the signal coupled to the adjacent conductor at the near end of the coupled line pair at port 4. This coupling is a function of

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the spacing and the length of the parallel lines with the maximum coupling occurring when the length is a multiple of ¼ wavelength. Coupling to the far end of the coupled line at port 3 is usually much less (typically about –20 dB) as long as the even and odd mode impedances of the coupled line pair are close to the nominal stripline impedance. This port (port 3) is usually referred to as the isolated port.

For many stripline designs, a via fence is placed on both sides of a stripline to suppress parallel plate mode propagation which could otherwise degrade the stripline circuit performance. In the case where two parallel striplines are routed close to one another, the two striplines often share a common via fence. A typical via fence structure for adjacent striplines is shown in Fig. 2.

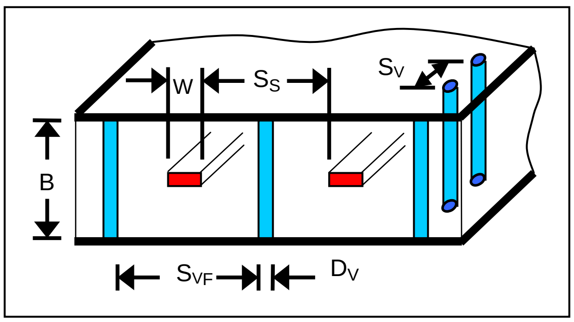

Fig. 2 - Typical Via Fence Structure

In this example two stripline conductors are enclosed on both sides by via fences which consist of a series of vias separated by a distance of S_V. The via separation S_V must be small (much less than a wavelength in the dielectric medium) in order to present an effective RF boundary. The spacing of via fences, S_{VF}, is chosen to be less than ½ wavelength at the highest operating frequency to form a below cutoff waveguide structure around each of the striplines. An example of two parallel striplines separated by a via fence was modeled using an EM simulator. The EM simulation model and its dimensional parameters are shown in Fig. 3.

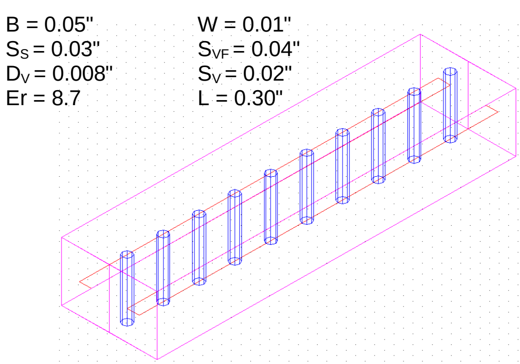

Fig. 3 - EM Model for Parallel Striplines with Via Fence

The modeled results of the coupling between the stripline conductors with and without the via fence are shown in Fig. 4a and 4b, respectively. Without the via fence, the near end coupling (S41) is about –24 dB maximum at the center of the band. The far end coupling (S31) is about –44 dB. The input return loss (S11) is less than –27 dB.

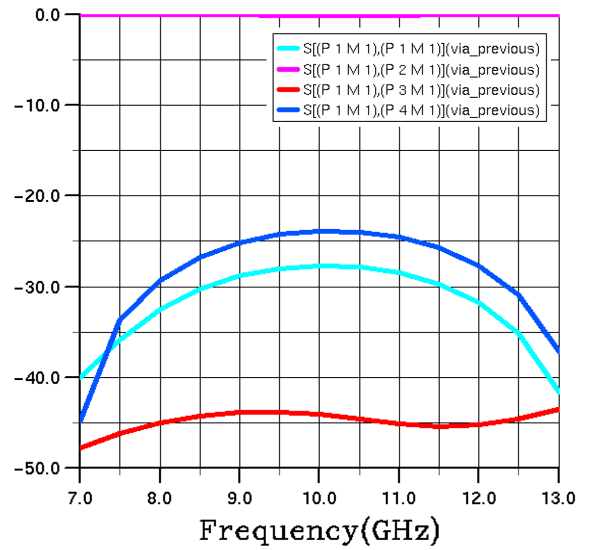

Fig. 4a - Simulation Results for Parallel Striplines without Via Fence

The modeled results *with* the via fence show the near end coupling (S41) to be –30 dB maximum and the far end coupling (S31) varying from –20 dB at the low end of the band to about –15 dB at the high end of the band.

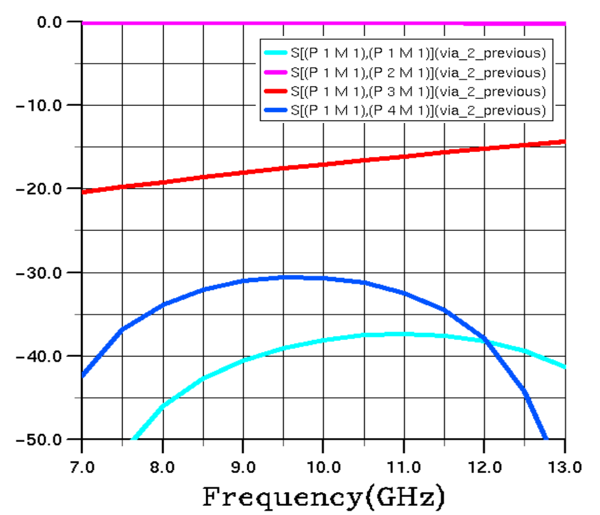

Fig. 4b - Simulation Results for Parallel Striplines with Via Fence

A comparison of the results show about a 6 dB reduction of the near side coupling (S41) for the circuit with the via fence between striplines, however the far side coupling (S31) is *increased* substantially, even exceeding the near side coupling. In addition, the far side coupling with the via fence exhibits a steady increase in coupling with electrical length at 6 dB/octave.

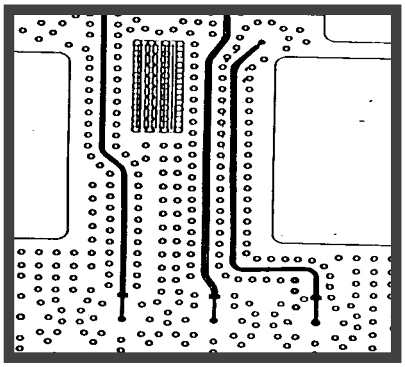

Fig. 5 - Design Example Circuit Layout

Fig. 5 shows an actual layout of two parallel striplines corresponding to the simulation model of Fig. 3. For this circuit the measured far side coupling was -18 dB at 10 GHz. This result agrees closely with the simulation result of –17 dB at 10 GHz shown in Fig. 4b.

In order to quantify this effect, EM simulations were preformed for various stripline conductor separations and stripline ground plane spacing. Fig. 6 shows values of near and far side coupling for parallel striplines with and without via fences versus the stripline conductor to ground plane spacing ratio (S_S/B) for values of 0.7 to 1.7. The results indicate a consistent reduction in near side coupling and enhancement of far side coupling when a via fence is used between striplines for a broad range of S_S/B ratios. The simulations also indicate that a large S_S/B ratio should be used to minimize crosstalk.

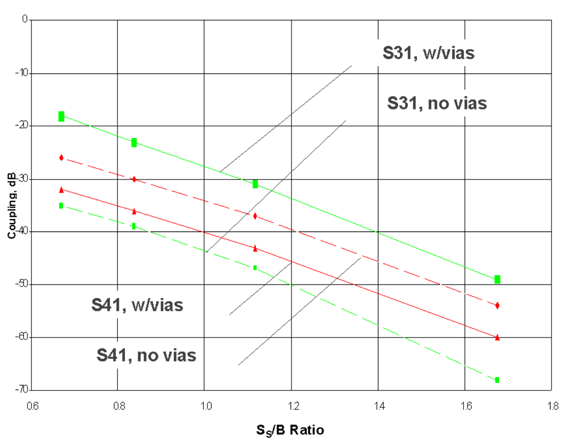

Fig. 6 - Coupling for Parallel Striplines vs. S_S/B ratio

IV. CIRCUIT MODEL OF VIA FENCE STRUCTURE

The coupling mechanism can easily be explained from a circuit point of view in terms of its even and odd mode operation. An equivalent circuit of the via fence structure of Fig. 3 is shown in Fig. 7. It consists of a cascaded network of short lengths of coupled stripline sections, representing the lengths of the coupled striplines between the vias, periodically shunted to ground with a series capacitor-inductor circuit. The capacitors represent the fringing capacitance of the striplines to each of the via posts. The inductors represent the via post inductances.

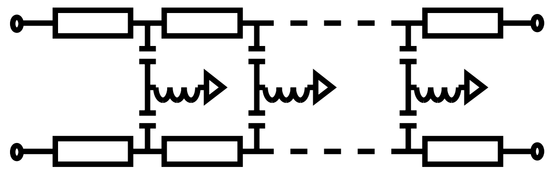

Fig. 7 - Equivalent Circuit of Close Proximity Striplines Separated by Via Fence

In the even mode, an open circuit may be placed at the midpoint of the circuit of Fig. 7 without affecting its result. In the odd mode, a short may be placed at the midpoint, thus shorting the inductor to ground. The even and odd mode half circuits are shown in Fig. 8. In the even mode circuit the shunt arms become series LC networks to ground. In the odd mode circuit the shunt arms become simple capacitors to ground.

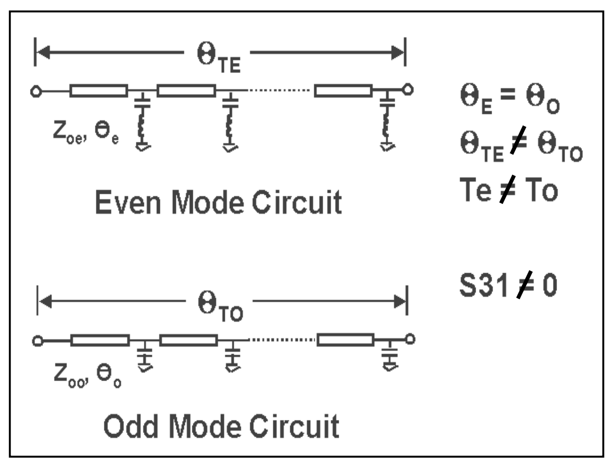

Fig. 8 - Even and Odd Mode Equivalent Circuits

Since stripline structures propagate TEM waves, the even and odd mode phase velocities are the same for the coupled stripline sections. Therefore, the incremental phase shifts for the even and odd modes are the same for each coupled line section. However, the phase shifts across the shunt arms for the even and odd mode circuits are different, and as a result the total phase shifts of the even and odd mode circuits are different. It is because of this phase shift difference that coupling to the far end is produced and increases as the electrical length of the circuit increases. This result is much the same as that of a microstrip directional coupler on a high dielectric constant material where the even and odd mode phase velocities are significantly different. Using a circuit simulator, the circuit of Fig. 7 was analyzed for the example shown in Fig. 3. The capacitance in the circuit was estimated to be 0.07pF and the inductance 0.10nH. The results are shown in Fig. 9.

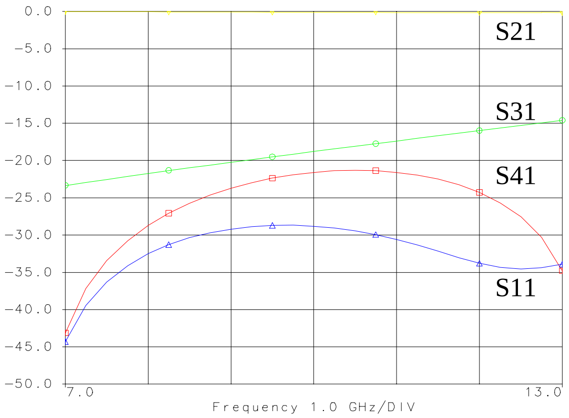

Fig. 9 - Circuit Simulation Results for Equivalent Circuit

As shown in the figure, the circuit simulator analysis shows a far end coupling of -19 dB at 10 GHz. This result agrees very closely to the EM simulation result of Fig. 4b (–17dB) and the measured result of –18 dB.

V. NEW VIA FENCE STRUCTURE

A new via fence structure that provides a significant reduction in both near end coupling and far side coupling between adjacent striplines is shown in Fig. 10.

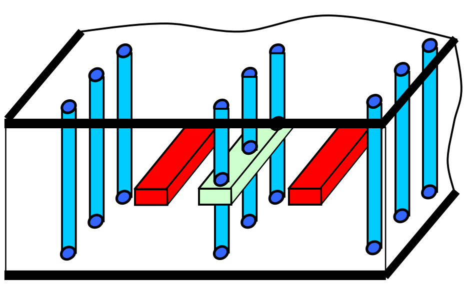

Fig. 10 - New Structure with Conductor Strip Added to Center Via Fence

This structure adds a conductor strip, on the same layer as the stripline conductors, which connects together the vias in the shared via fence. In addition, if the stripline stackup consists of several layers, additional conductor strips can be added to connect vias on each layer, providing an even greater reduction in crosstalk. An EM simulation was performed on the model of Fig. 3 modified to include conductor strips on five layers connecting the vias. The results are shown in Fig. 11. The far side coupling (S31) is reduced from the prior result of -17 dB to -52 dB at 10 GHz, a 35 dB improvement. In addition, the near side coupling (S41) was reduced from -30 dB to -60 dB. To verify these results experimentally, the layout of Fig. 5 was modified to include conductor strips on five layers and a new circuit was fabricated. The near and far side couplings measured -65 dB and -50 dB respectively at 10 Ghz. These values compare very well with the simulated results of -60 dB and -52 dB.

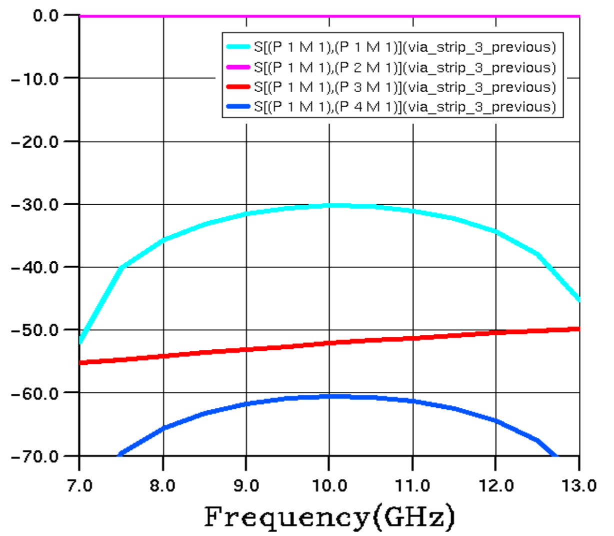

Fig. 11 - Near and Far Side Coupling for Via Fence with Five Conductor Strips

VI. CONCLUSION

EM simulations show that when a via fence is placed between two closley spaced striplines, the near end coupling is reduced while the far end coupling may be substantially increased. A new via fence structure that uses conducting strips to connect the vias is presented that reduces the coupling by 30 dB or more. The new via structure's performance was experimentally verified and the measured results agreed very closely to the simulated performance.

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