

Full-wave Analysis and Characterization of Via Grounding Techniques Used To Isolate Striplines For Embedded Passive Interconnects

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Abstract: Multilayer electronic packages commonly use striplines as electrical interconnects between various RF and microwave devices, including embedded passives, in MCMs. It is a generally accepted practice in multilayer packages to use vias to ground the top and bottom metal planes of the stripline structure in order to improve the isolation between critical stripline interconnects. In this paper, full-wave electromagnetic solvers and measurements are used to characterize the isolation between two parallel striplines in Dupont 943 LTCC substrates of various thicknesses. A via fence of varying via number and via pitch is placed between the striplines. As substrate thickness increases, isolation between striplines decreases. As compared to having no via fence, it is shown that via fences with increasingly tighter via pitches increasingly improve isolation for the near-end cross coupling. However, for the far-end coupling, the introduction of a via fence can actually significantly increase coupling and thus degrade isolation between striplines.

Keywords: LTCC, Striplines, RF Via, Coupling, Isolation

I. Introduction

The trend in electronic packaging toward higher density routing, multichip modules (MCM), and embedded passive devices leads to an increased probability of undesired crosstalk between devices. Coupling between signal traces can lead to false signaling, reduced circuit performance, and even system failure. To reduce the probability of cross talk, metal filled vias are usually used to improve isolation between signal traces [1].

For high density routing, the most common transmission line structure used for electrical interconnects is the stripline. The stripline is a TEM mode structure having a signal trace positioned parallel between two metal planes. The advantage of the stripline structure is that the signal trace is shielded from components external to the metal planes. However, additional methods are required for providing isolation between signal traces that exist between the same two metal planes. Isolation between striplines is most typically accomplished by placing via fences as an electromagnetic wall to decrease coupling between signal paths.

A leading material technology for MCMs and packages requiring embedded passive capability is Low Temperature Co-fired Ceramic (LTCC). LTCC materials have relatively low dielectric constants, use the high conductivity precious metals such as gold, silver, and copper for conductors, and also have very low dielectric losses into the multi-GHz ranges. In this paper we have chosen Dupont 943 LTCC as the material technology. The 943 material has a dielectric constant of 7.4 and a loss tangent of 0.002 at 40GHz.

Since the cost of a package is directly proportional to the amount of metal in the package, there is a strong motivation to reduce cost by reducing the amount of metal in a package while simultaneously not sacrificing electrical performance. To investigate the possibility of reducing the number of vias used for isolating striplines in a package, a full-wave electromagnetic modeling and analysis approach is used. In this paper, the full-wave electromagnetic solver HFSS is used to qualify and quantify the use of a via-fence structure for increasing isolation at both the near-end and far-end of two parallel striplines. We evaluate coupling as a function of substrate height and the pitch of the vias in the via-fence. It is shown that thinner substrates, as expected, can provide high isolation. It has been

previously shown that for via fences that are very close to a stripline structures, coupling can actually increase [2]. For near-end coupling, via fences slightly improve isolation over not using a via fence in general, but results were inconclusive. A via-fence with a grounding strip has been demonstrated to exhibit high isolation at both near- and far-end [3]. However, the focus of this work was on methods to increase isolation and reduce the amount of metal in a package. For the far-end, the use of a via-fence was found to significantly increase the cross coupling. In all cases simulated, the vialess fence provided the largest far-end isolation. To validate this conclusion, Dupont 943 stripline structures were fabricated and far-end coupling measurements taken. Agreement between measurement and simulation is excellent.

II. Full-wave analysis of Coupled Striplines

Figure 1 illustrates the stripline structure for the analysis of coupling between two parallel striplines. The material is Dupont LTCC 943, which has a dielectric constant of 7.4 and a loss tangent of .002 at 40 GHz. The structure is 480 mils long, and is parameterized in HFSS for studying the impact of substrate thickness, H , gap spacing, G , and via pitch, P , on the near-end (S21) and far-end coupling (S41).

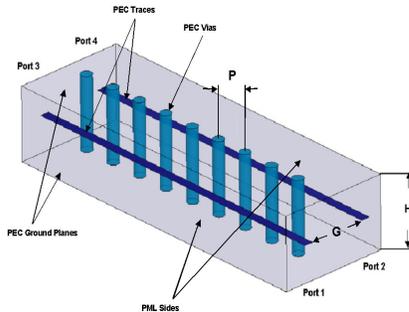


Figure 1. Two parallel striplines with substrate height, H , separation, G , and a via-fence with via pitch, P .

To provide a benchmark simulation, the structure is simulated with no vias, i.e. an infinite via pitch, P . The simulated results for the near end coupling as a function of substrate height is shown in Figure 2. The substrate height is varied from 18 mils to 26 mils. The stripline spacing is kept constant at 15 mils, and the stripline widths are varied to maintain a 50-ohm system for each substrate height. The simulation is varied from 1 to 20 GHz. It is clear from Figure 2 that for this no-via fence case, the coupling increases as frequency increases and as substrate height increases. However, as is well known, thinner substrates will incur higher losses, which will be a

tradeoff design parameter in their use to reduce coupling.

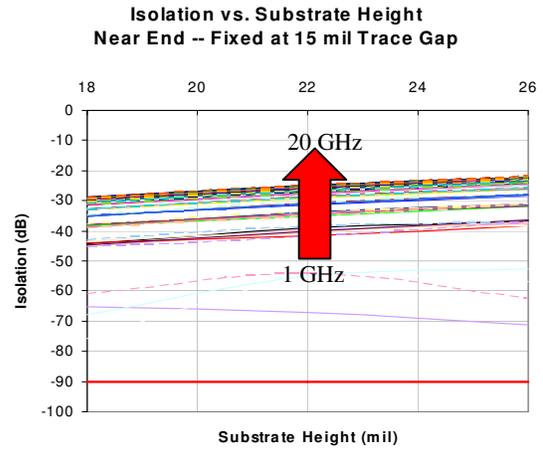


Figure 2 Near-end isolation as a function of frequency and substrate height. $G = 15$ mils.

As shown in Figure 3, the coupling at the far-end (S41), for the case of no via fence, also exhibits increased coupling as frequency and substrate height increases. However, the trend is not as linear as the near-end case, and in particular, at two frequencies, 6.25 GHz and 6.5 GHz, the general trend of increasing isolation with decreasing substrate height is markedly different from the results at other frequencies. This suggests that a more complex coupling behavior is occurring at the far-end, S41. At frequencies where the stripline length is close to an odd multiple of a quarter-wavelength, we see the worst-case effects of having imperfect port terminations, i.e. the coupled energy will reflect, re-couple, re-reflect, and so on. So, as is well known, coupling is a function of load conditions.

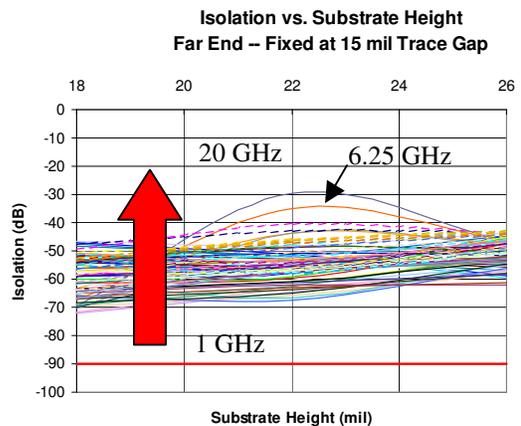


Figure 3 Far- isolation as a function of frequency and substrate height. $G = 15$ mils.

To investigate the far-end coupling as a function of via pitch of the via-fence, a number of cases were examined. Figure 4 illustrates the far-end coupling, S_{41} , as a function of via pitch and frequency for a stripline structure of substrate height 18 mils and stripline gap of 15 mils. The pitch limits, as illustrated in Figure 4, are a solid wall, representing a via pitch of 0 mils, and an infinite pitch, representing the case of placing no via-fence between the striplines. The frequency is varied from 1 GHz to 20 GHz, the substrate height, H , is fixed at 18 mils, and the gap, G , is fixed at 15 mils. From our previous results we might expect that coupling increases as a function of increasing frequency, which is clearly the case as shown in Figure 3. Also, intuitively, it would seem that the introduction of tighter via pitches would improve the isolation of the far-end ports. Indeed this is the case for via pitches less than about 15 mils. However, a via-fence with via pitches below 20 mils would represent a design guideline violation for vias having 10 mil diameters and hence would not be manufacturable. In addition, the simulations clearly show that the isolation for the far-end coupling, S_{41} , is severely degraded for cases where the via pitch is between 20 mils and 30 mils. The best isolation at the far-end, for all frequencies, is achieved for the practical case where no via fence is present.

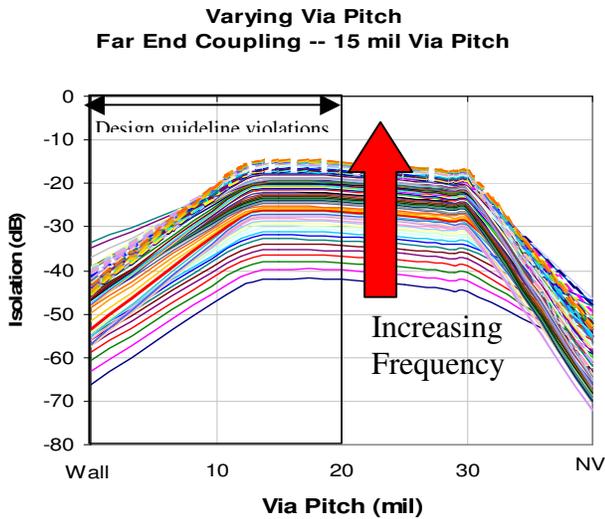


Figure 4. Far-end coupling as a function of frequency and via-fence via pitch. The substrate height, $H=18$ mils, and the gap, $G=15$ mils.

The impact of a via fence on the near-end coupling suggested slight improvement as the via pitch of the via-fence tightened.

III. Measurements vs. Simulations

To validate the conclusions for the far-end coupling based on the previously discussed simulations, a measurement test structure was designed as shown in Figure 5. The substrate thickness for the stripline section was 26 mils, the gap between the striplines was 18 mils, and the coupled stripline length was 400 mils. For ease of probe measurement, a surface coplanar waveguide structure electrically connected to the striplines with signal and ground vias was designed. The simulated near-end coupling and far-end coupling is shown in Figure 7 and Figure 8, respectively. Figure 7 shows the near end coupling for no via-fence case, a 20 mil via pitch, and a 40 mil via pitch via-fence for a frequency range from 1 GHz to 20 GHz.

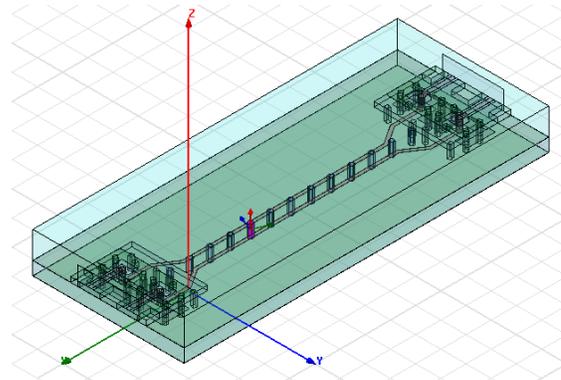


Figure 5. Model for test structure. CPWG probe launches to stripline. Substrate height, $H=26$ mils, gap, $G=18$ mils.

For the structure of Figure 5, the results do not support the addition of vias for improving near end coupling. In general for the higher frequencies, the no-via fence case is seen to be best, however, all cases include ground vias in the near-end vicinity for the RF via to stripline transition. This could be a contributing factor in the coupling in the near end.

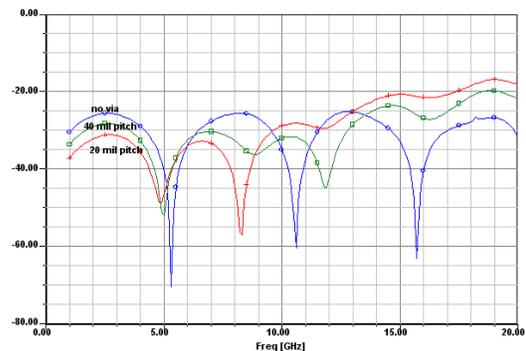


Figure 7. Near-end coupling for cpwg to stripline structure.

Figure 8 clearly shows that the addition of a via fence increases the far-end coupling quite significantly. The 20 mil via pitch, which would otherwise be thought to provide the best isolation since it has the tighter via pitch, actually provides the least amount of far-end isolation

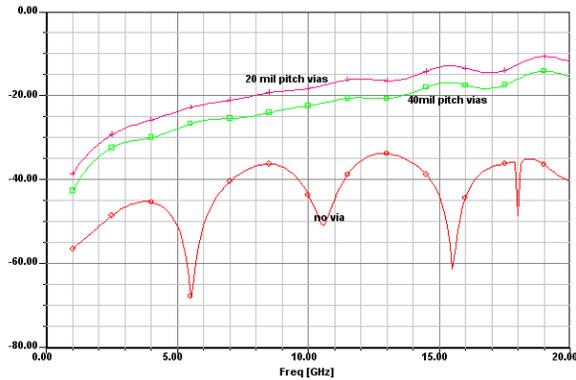


Figure 8. Far-end isolation for no via-fence case, 20-mil pitch case and 40 mil via pitch case.

Measurement correlation and validation of simulation for the no-via and 40 mil via pitch fence is shown in Figure 9. The simulation and the measurement agreement is very good and validates by measurement that the far-end coupling is seriously degraded by the introduction of a via fence.

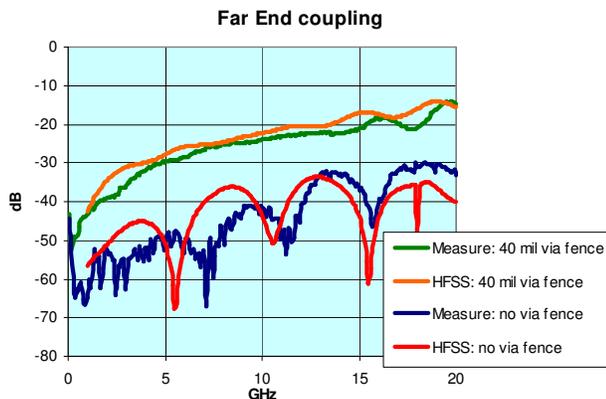


Figure 9. Measured vs. simulation for far-end coupling for Dupont 943, substrate height, H = 26 mils.

IV. Conclusions

There are a number of methods for improving isolation between striplines that run parallel to each

other over a significant electrical length. Simply increasing the distance can, of course, increase the isolation. However, this method may not be an option for high-density package designs. The isolation has been shown to be best for thinner substrates. However, the caveat for this method is that this option may be limited by insertion loss requirements. Using a via-fence between two tightly coupled striplines does improve isolation, but it does so at via pitches that are not manufacturable. In addition, for via fences that are manufacturable, the far-end isolation is significantly degraded as compared to having no via fence. For the near-end isolation afforded by using a via-fence, inconclusive results warrant further numerical studies. For the far-end isolation, the highest isolation occurs for the case where the via-fence is not present.

Acknowledgements:

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