How Long is Too Long? A Via Stub Electrical Performance Study

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Abstract

As signal frequencies increase into the multi-GHz range, via structures become more important in an electrical design. Via stubs can severely degrade multi-Gbps signals, especially if they create resonances and reflections at frequencies that the signal excites. There are several ways to mitigate via stub problems. This paper investigates minimizing via stubs through multiple sub-composites in a circuit board and compares results to a full Z-interconnect, zero stub board. S-parameters are measured for each net. Results show the effect of via stubs of various length and are contrasted with zero via stubs and full Z-interconnect.

Author(s) Biography

Michael Rowlands is an Electrical Engineer in the Research and Development department at Endicott Interconnect Technologies. He specializes in signal integrity at gigahertz frequencies. He received a Bachelor's and Master's degree in Electrical Engineering from MIT in 1998. After college, he worked four years as a signal integrity engineer at Teradyne in Boston. He designed cable assemblies, circuit boards and interconnects for test equipment up to 6 GHz. He then worked three years at a startup company in Illinois. The company designed dispersion compensation microchips at 12.5 Gbps for fiber-optic communications. He designed circuit boards to demonstrate and verify 12.5Gbps performance and made algorithm improvements based on modeling the entire system. He has presented several papers at ECTC, IMAPS, IPC-APEX and PCB East. For the past three years he's worked in Research and Development at EI as a signal integrity engineer where he designs and measures EI technologies and works to improve them.

Introduction

This investigation focuses on via stubs since they can easily degrade signals in the gigahertz. [1] In order to investigate via structures at multi-GHz frequencies, test vehicles are built. It can be difficult to get a good model of a via without extensive calculations or full 3D modeling. Rather than a restrictive design rule for via stubs such as “near zero” or “as small as possible,” this paper shows hard data to inform a design engineer about how long a via stub designs can tolerate. A set of measured data is collected to covered a variety of via structures. Vias are configured to have no stubs or long stubs (~80 mils) to short stubs (~10 mils). Measurements are made with a Network Analyzer, on stripline structures of various length and various via configurations. Frequencies 1MHz to 20GHz are used to generate S-parameters. Another structure measured is a full Z-interconnect board, which has zero via stubs on all signal layers and has controlled via structures to maximize high frequency performance.[2,3]

Test Vehicle Description

The via stub test vehicles has 12 metal layers, 4 of these are signal layers. There are 7 different line widths ranging from 3 mils to 16 mils. Each of those line widths have 3 different lengths of stripline, 10 cm, 30 cm and a very long length, up to 170cm. Each of the 21 stripline combinations have 3 different via stub configurations: zero stub, full plated-through-hole, and a via stub from a blind and buried via stack. The material used in the test vehicle is Megtron 6. This is a fairly low-loss material that’s still glass-filled and easy to manufacture. The dielectric constant of Megtron6 is about 3.5 and the loss tangent is about .007 at 1GHz.

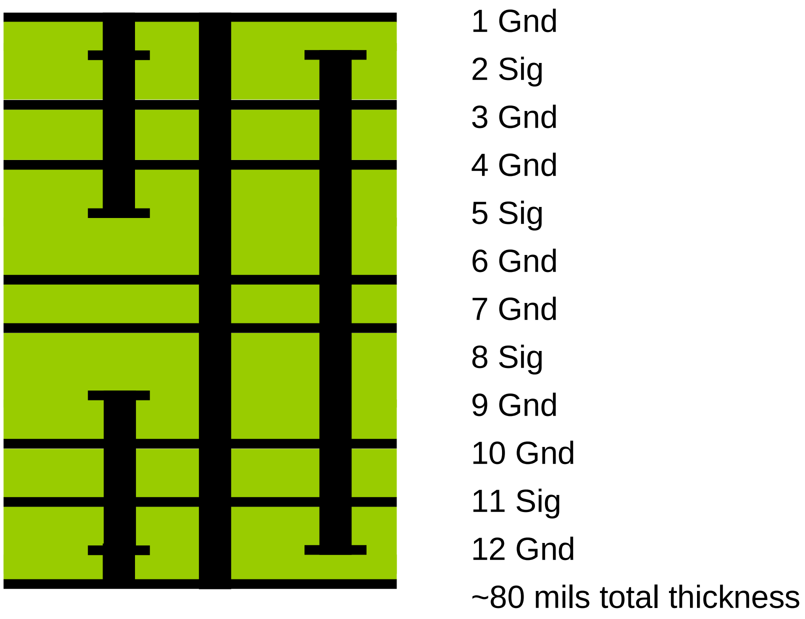


Figure 1 Test Vehicle Stack-up

Via configurations were varied throughout the sequential laminate structure. Plated-through holes were the simplest, straight through the board. Zero via stub configurations were either a blind via going from the top layer to the signal layer, or a combination of a blind via down to a certain layer, then a buried via back up the exact signal layer. Different via stub lengths were created by using blind and buried vias. There were several down-and-up via configurations as well as single via structures, as in **Table 1**. The down-and-up via configurations were constructed to intentionally add via stub length or creatively to reduce via stubs. This is shown in **Figure 2**. Let’s define “PTH” stubs as the via
stubs created from a single plated-through-hole to distinguish them from intentional stubs built from buried and blind vias. The term “down-and-up zero via stub” is used to note a zero stub configuration that includes a PTH to the bottom layer and then one back up to the appropriate signal layer. This distinguishes it from zero via stubs that can be constructed directly from blind and buried vias.

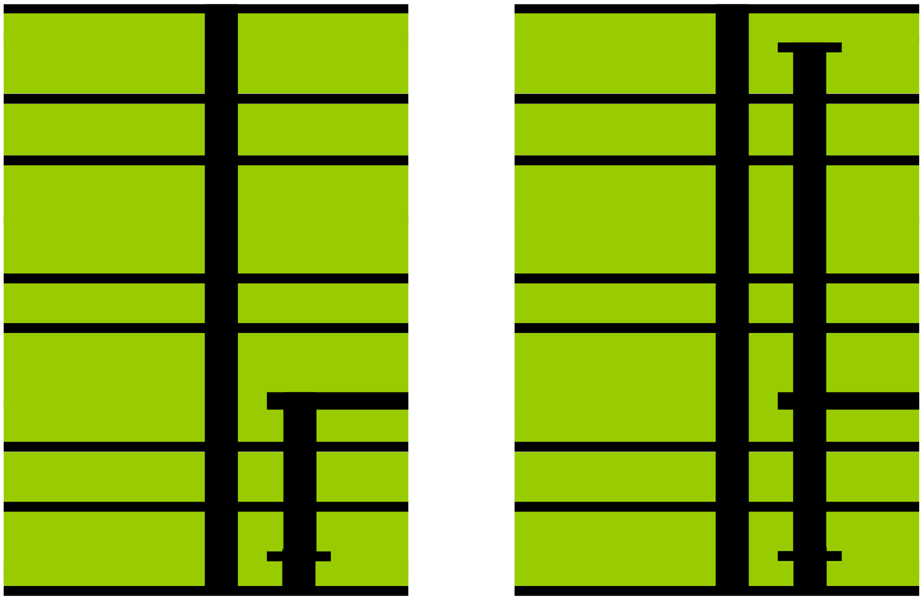


Figure 2 Down-and-Up Via Configurations

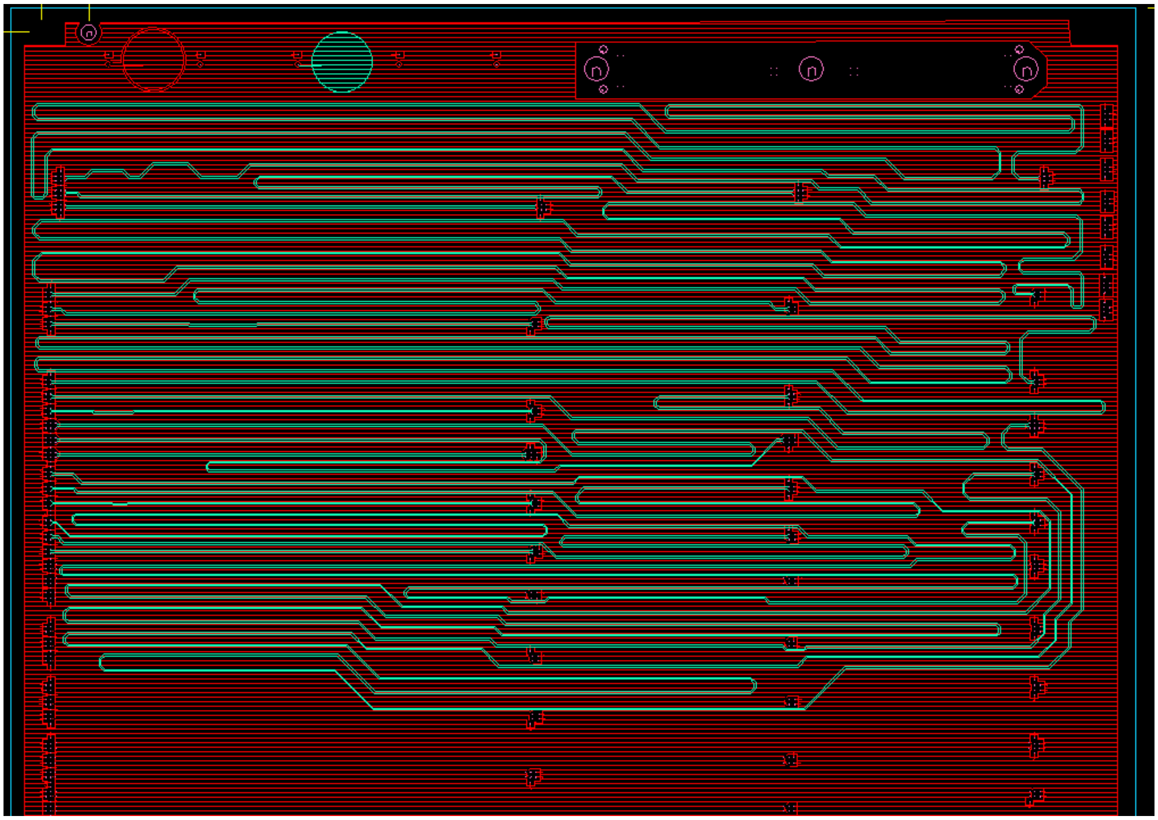
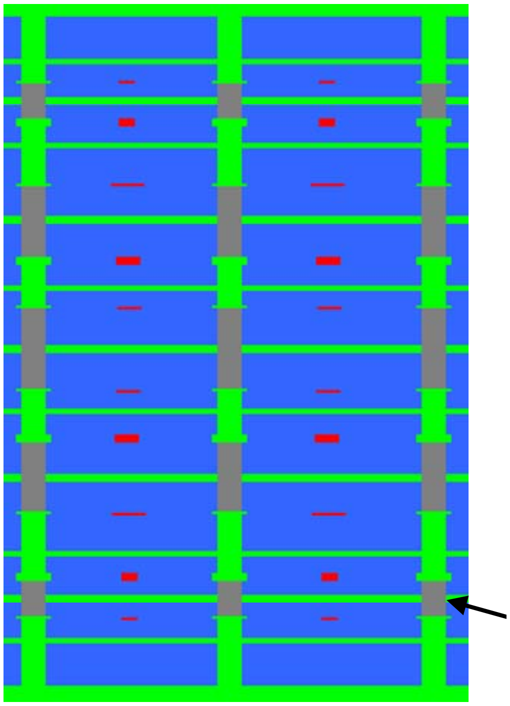


Figure 3 Snapshot of Test Vehicle Design

Table 1 Test Vehicle Design Summary

Layer	Trace Width	Differential Spacing	Plane Top	Plane Bot	Zdiff	Net Lengths (cm)	PTH Stub length	Intentional Stub Length
L02	4.5	9.20	L1	L4	100.0	10, 30, 60	7.68	73.92
L05	8.0	6.20	L7	L3	100.0	10, 30, 80	57.88	31.4
L05	10.0	6.00	L9	L1	100.0	10, 30, 100	57.88	23.72
L08	6.0	4.60	L6	L10	100.0	10, 30, 110	31.4	50.2
L08	13.0	7.70	L4	L12	100.0	10, 30, 130	31.4	57.88
L08	16.0	9.60	L4	L12	100.0	10, 30, 150	31.4	50.2
L11	3.0	5.40	L12	L10	100.0	10, 30, 170	81.6	23.72

Another test vehicle is a full Z-interconnect structure. Manufacturing a Z-interconnect substrate involves building mini-substrates (sub-composites) of 2 or 3 layers each, then assembling several mini-substrates together to make the finished product. “Z-interconnect” is used to connect metal layers vertically, using a conductive adhesive. A Z-interconnect stack-up is achieved using joining cores, which are a copper plane with dielectric laminated on each side, then drilled and filled with conductive paste. Signal building blocks, typically 3 or 4 metal layers, are stacked together with a joining core in between. This composite structure is laminated under controlled temperature and pressure to create the final board.



23 metal layer stack-up
6 2S1P signal cores
5 0S1P joining cores
11 planes
top, bottom metal
10 signal layers
(SKETCH NOT TO SCALE)

Figure 4 Full-Z Board Stack-up

Results

Measurements are made using a Network Analyzer up to a frequency of 20GHz and s-parameters are recorded. On layer 3, the signals plotted in **Figure 5** are 3 mils wide, with via stubs of 0, 24 and 81 mils, and lengths of 30 and 60 cm. The 24 mils via stubs are actually slightly better up to 20GHz. The 81 mils stubs have a first resonance at about 15GHz.

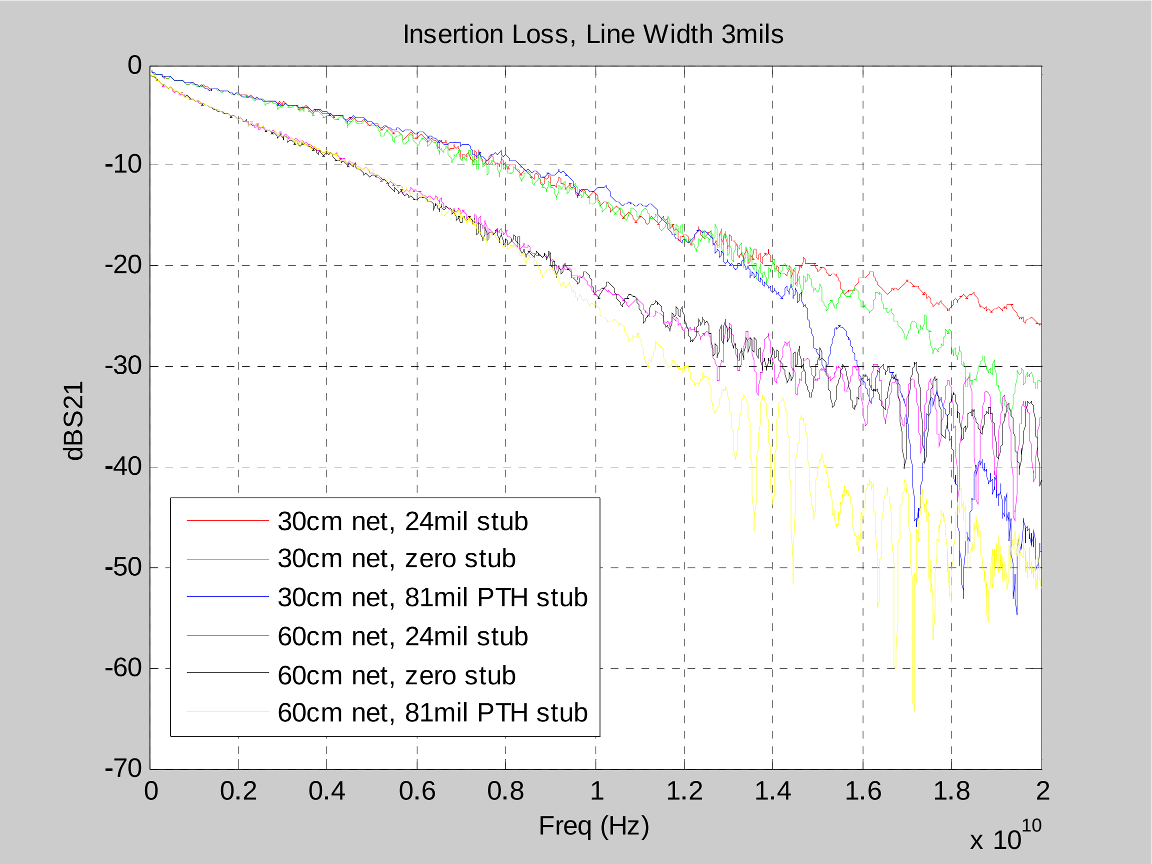


Figure 5 Measurements on 3 mils Line Width Nets

On layer 11, the signals plotted in **Figure 6** are 4.5 mils wide, with via stubs of 0, 74 and 8 mils, and lengths of 30 and 60 cm. The 8 mils via stubs are hardly noticeable up to 20GHz. The 74 mils stubs have a resonance at about 13GHz.

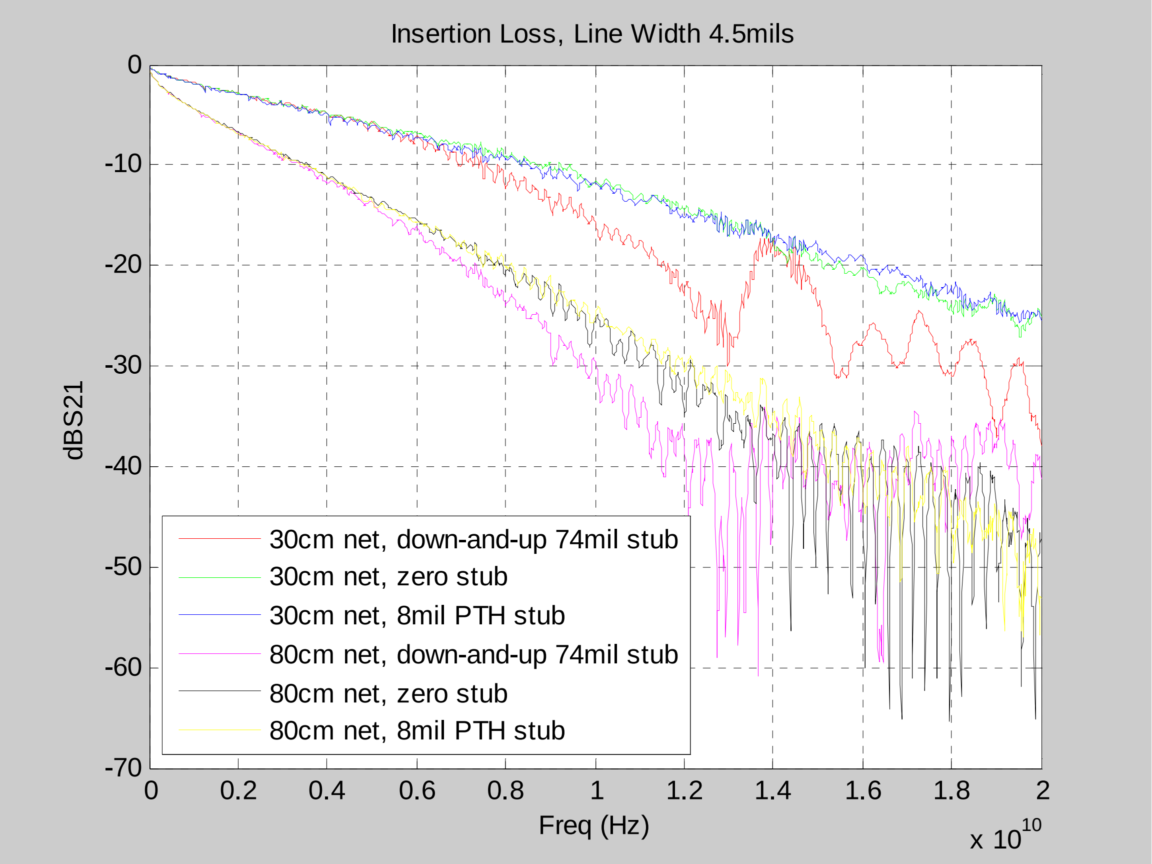


Figure 6 Measurements on 4.5 mils Line Width Nets

On layer 5, the signals plotted in **Figure 7** are 8 mils wide, with via stubs of 0, 31 and 58 mils, and lengths of 30 and 80 cm. The 31 mils via stubs noticeable up to 20GHz but have a resonance above 20GHz. The 58 mils stubs have a resonance at about 19GHz. It is clear that with the 58 mils stubs on the longest net, 110cm, there is another resonance effect at about 13GHz. It is broader and lower frequency than the 19GHz resonance. The combination of the long via stub with the long net causes significant degradation in the signal path.

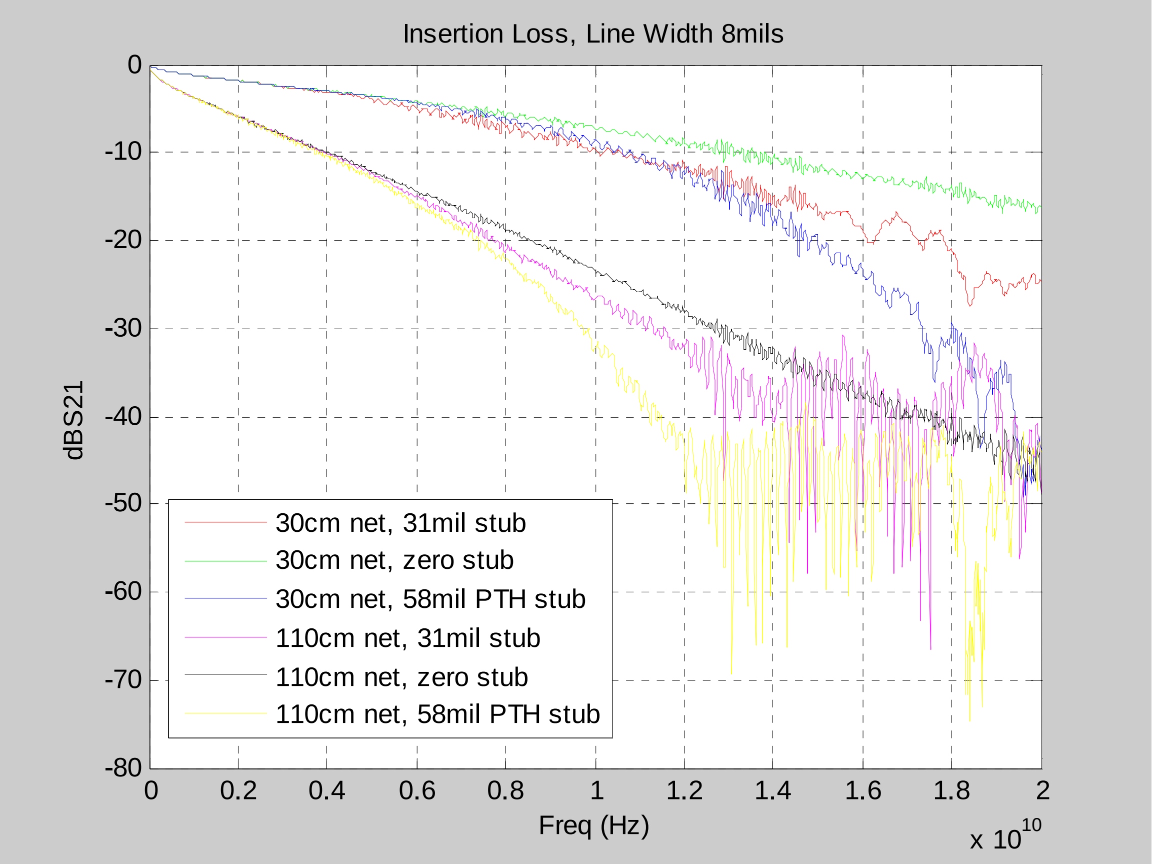


Figure 7 Measurements on 8 mils Line Width Nets

On layer 5, the signals plotted in **Figure 8** are 10 mils wide, with via stubs of 0, 24 and 58 mils, and lengths of 30 and 130 cm. The 24 mils via stubs are noticeable up to 20GHz but have a resonance above 20GHz. The 58 mils stubs have a resonance at about 19GHz. The 24 mils stubs on the longest net, 130cm, has a resonance effect at about 9GHz. The via stub-long net effect with the 58 mils stub is at about 17GHz.

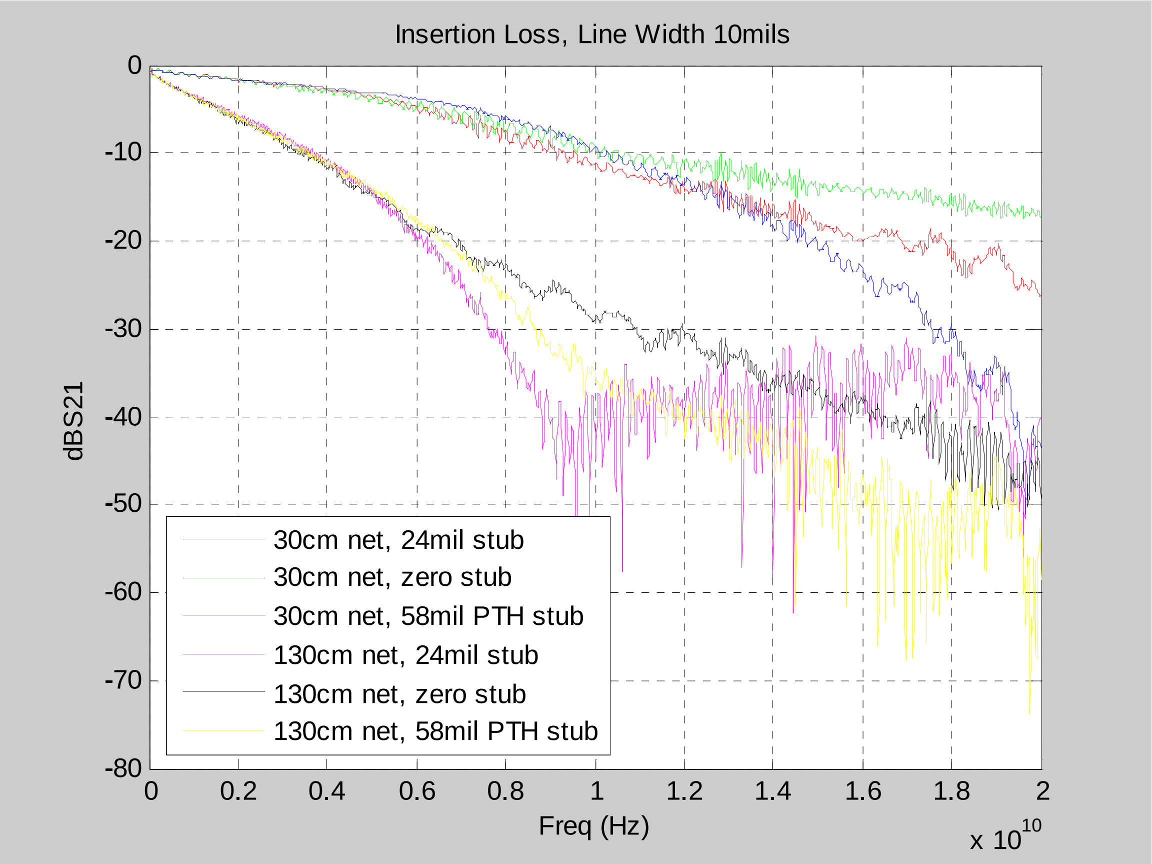


Figure 8 Measurements on 10mil Line Width Nets

On layer 8, the signals plotted in **Figure 9** are 6 mils wide, with via stubs of 0, 50 and 31 mils, and lengths of 30 and 100 cm. The 31 mils via stubs are noticeable up to 20GHz but have a resonance above 20GHz. The 50 mils stubs have a resonance at about 17GHz. The down-and-up zero via stubs are not better than the 31 mils stubs. On the 100cm net, all 3 via configurations have approximately about the same performance below 14GHz. The 50 mils stub on the longest net shows a resonance at about 15GHz.

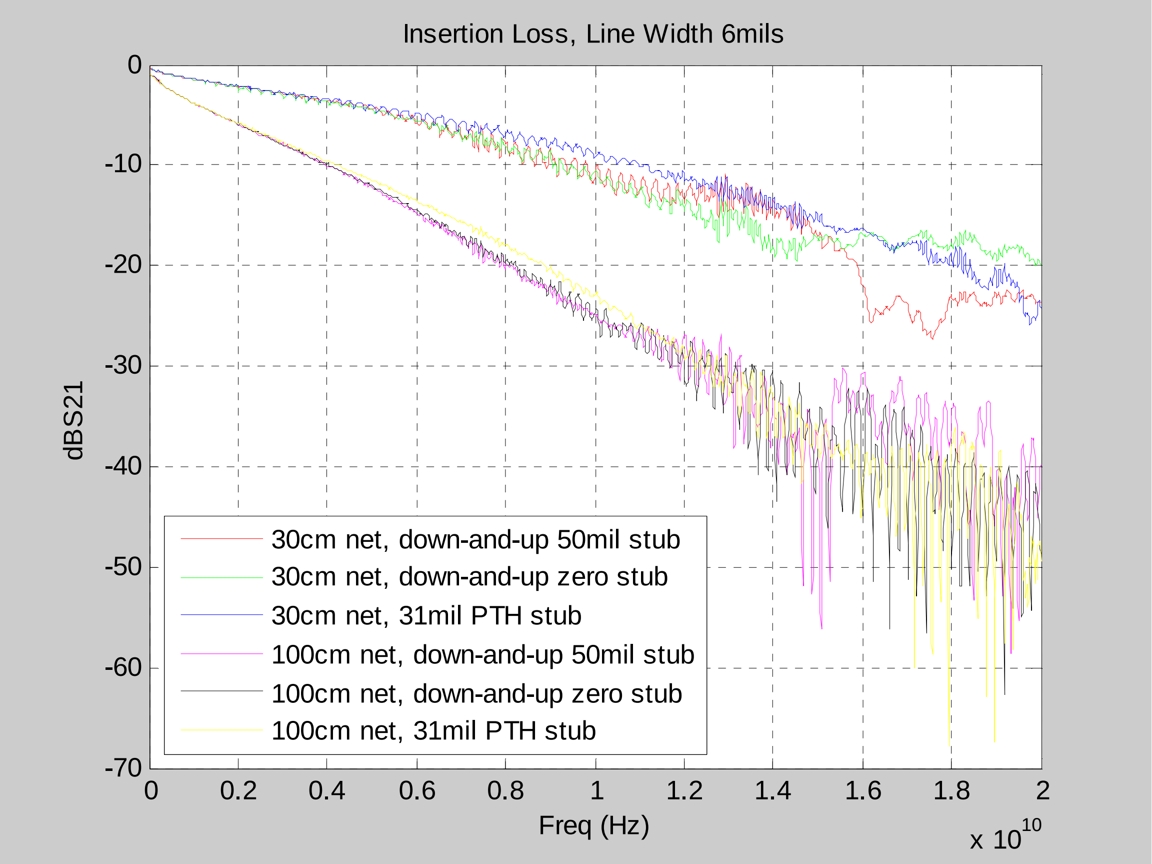


Figure 9 Measurements on 6 mils Line Width Nets

On layer 8, the signals plotted in **Figure 10** are 13 mils wide, with via stubs of 0, 58 and 31 mils, and lengths of 30 and 150 cm. The 31 mils via stubs are noticeable up to 20GHz but have a resonance above 20GHz. The 58 mils stubs have a resonance at about 19GHz. The down-and-up zero via stubs are not better than the 31 mils stubs. In fact, on both 30cm and 150cm nets, the down-and-up vias have a resonance around 13GHz. On the 150cm net, the zero stub configuration is clearly the worst performance of the 3 configurations; it has a large decrease in transmission near 5GHz.

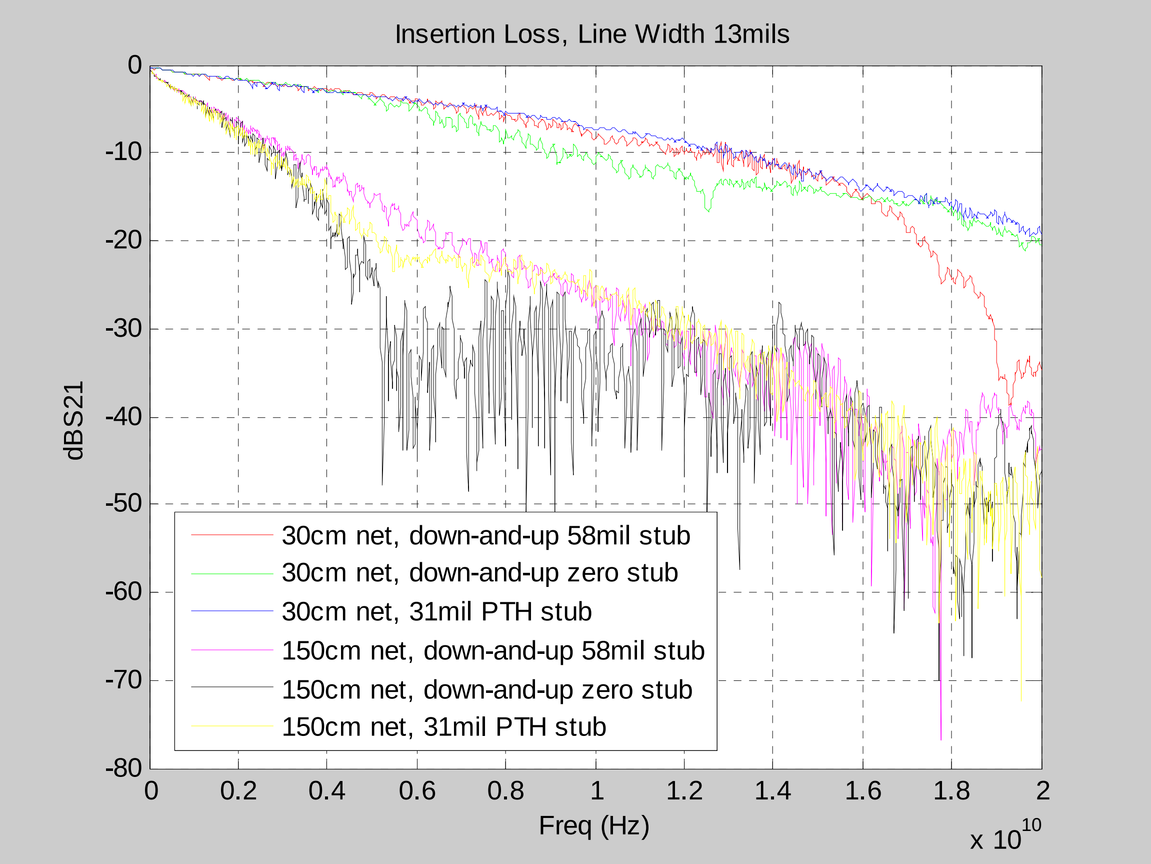


Figure 10 Measurements on 13 mils Line Width Nets

On layer 8, the signals plotted in **Figure 11** are 16 mils wide, with via stubs of 0, 50 and 31 mils, and lengths of 30 and 170 cm. The 31 mils via stubs are noticeable up to 20GHz, but have a resonance above 20GHz. The 50 mils stubs have a resonance at about 20GHz. The down-and-up zero via stubs are not better than the 31 mils stubs. In fact, on both 30cm and 170cm nets, the down-and-up vias have a resonance around 13GHz. On the 170cm net, the zero stub configuration is just as bad as the 50 mils stub. They have significant signal loss near 5GHz.

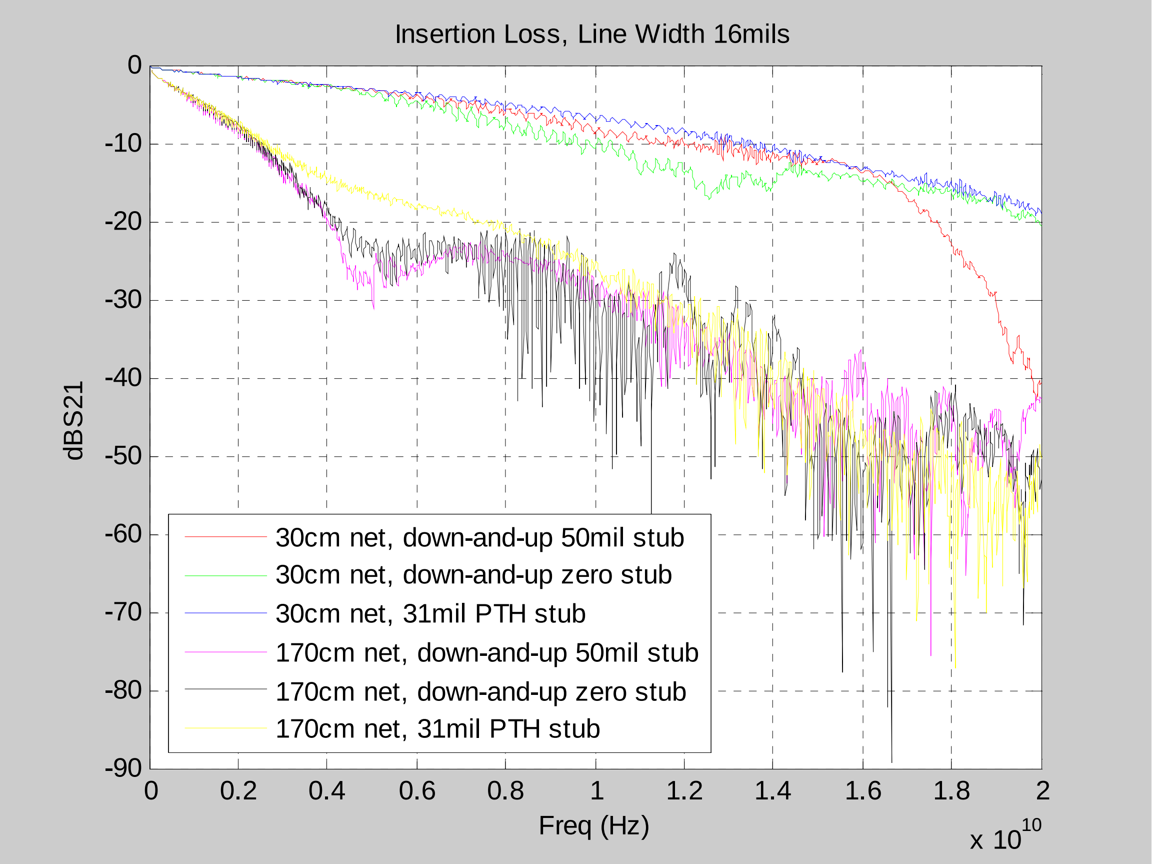


Figure 11 Measurements on 16 mils Line Width Nets

The Full-Z results showed fairly smooth, low-loss signal transmission with 5 mils wide line and 45cm length. Full-Z enables zero via stubs on all nets. This construction eliminates all the various resonances, loss and discontinuities seen in the via stub test vehicle.

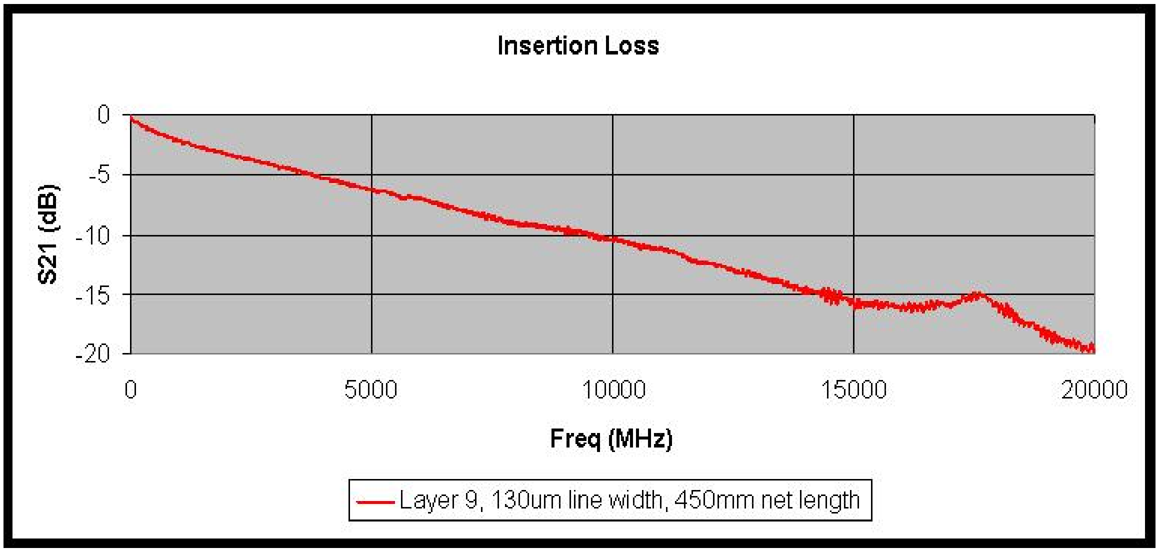


Figure 12 Measurements on Full-Z, 5 mils Line Width Net

Via Modeling

In order to understand the measurements seen in the previous section, simple via models were used. Many more involved, highly accurate via models have been developed recently [4], but simple models are informative for this test vehicle. The via stub was modeled as a cascade of co-axial and parallel cylinder transmission line structures. The co-axial transmission-line model is used for a via and anti-pad geometry found in vias as they pass through metal planes. The parallel cylinder model is used for a signal via with a ground via next to it in between metal planes. A diagram of the model is shown in **Figure 13**.

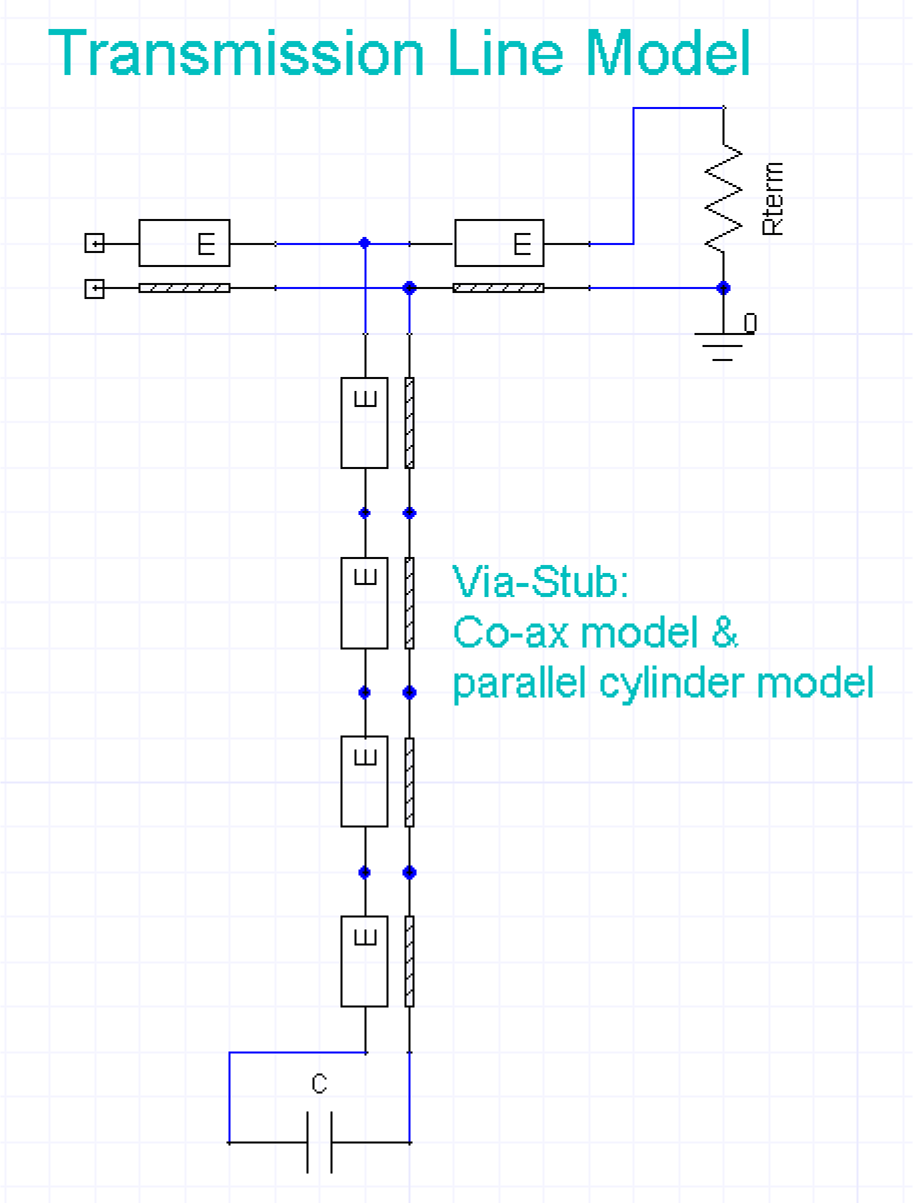


Figure 13 Via Model using Simple Transmission Lines

Using the via model, a set of insertion loss curves were plotted for a range of via stub lengths. The model fits reasonably well with the measurements. Measurements show an 8 mils via stub having little effect on loss to 20GHz, while a 30 mils via stub causes some loss, having a primary resonance well above 20GHz. The models shows resonance at about 28GHz for 30 mils via stubs. At stub length of about 60 mils, the model shows a resonance at 16GHz, while measurements showed it at 19GHz. For the longest stubs in the study, 74 mils, the measurements had a resonance at 13GHz, which is right about what the model calculates.

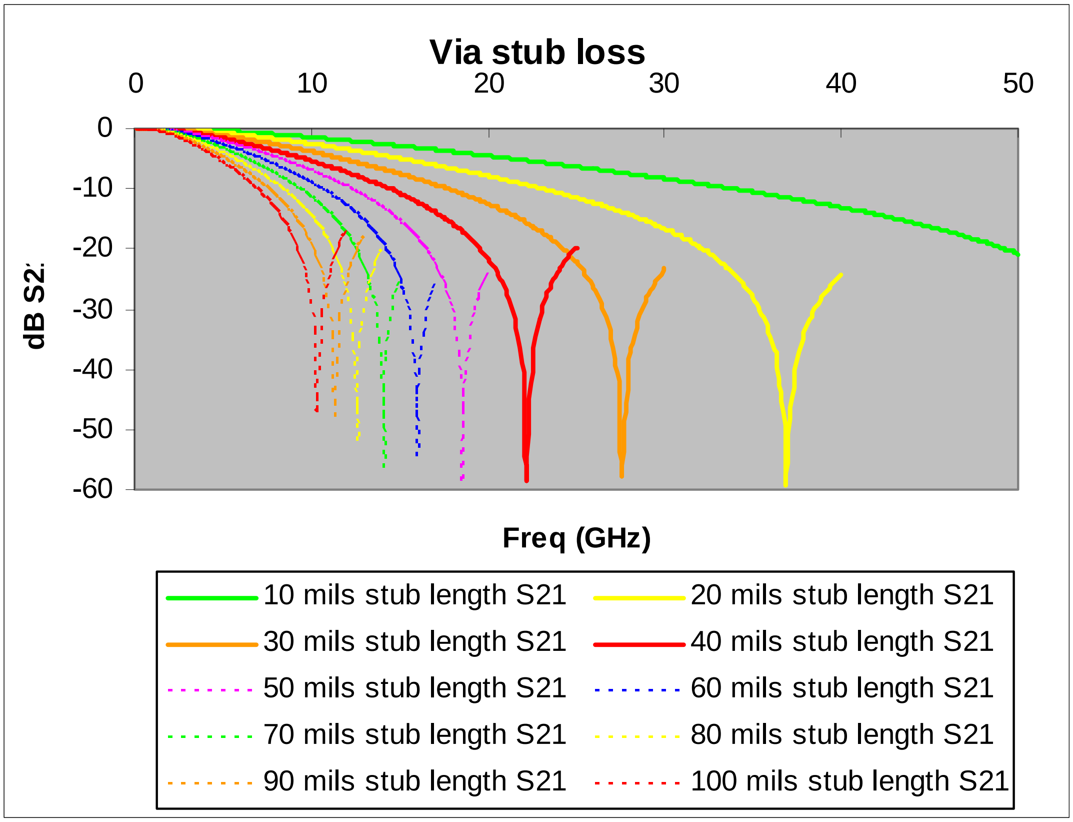


Figure 14 Results of Via Stub Simple Model

The simple model indicates that the via stub resonance and overall loss is very sensitive to the parasitic capacitance at the end of the stub. If a via pad at the end of a via stub, is large and over a solid ground plane, it can significantly impact the signal path. For instance, in the model, changing that end capacitance on a via stub, from 0.1pF to 1pF can move the resonance from 13.6GHz to 6.8GHz.

Therefore, based on the model, it is theorized that in **Figure 9** there is a little excess capacitance that pulls the resonance down to 17GHz vs. a 19GHz resonance on a similar via stub in **Figure 10**. Upon examining the design, it is true that the 17GHz stub has a ground plane on the next layer at the end of the via stub, whereas the 19GHz stub has a clearance on the next layer at the end of the stub. The extra capacitance to ground moves the via stub resonance down to 17GHz.

Another question that comes to mind, based on the data, concerns the down-and-back via configurations. Why are the zero via stubs with down-and-back vias similar to large via stubs? After modeling the vias using RLC's with coupling, there is an explanation. **Figure 11** shows a big discontinuity and bad resonance structure. A PTH via stub performs better than a "down-and-up" zero via stub structure.

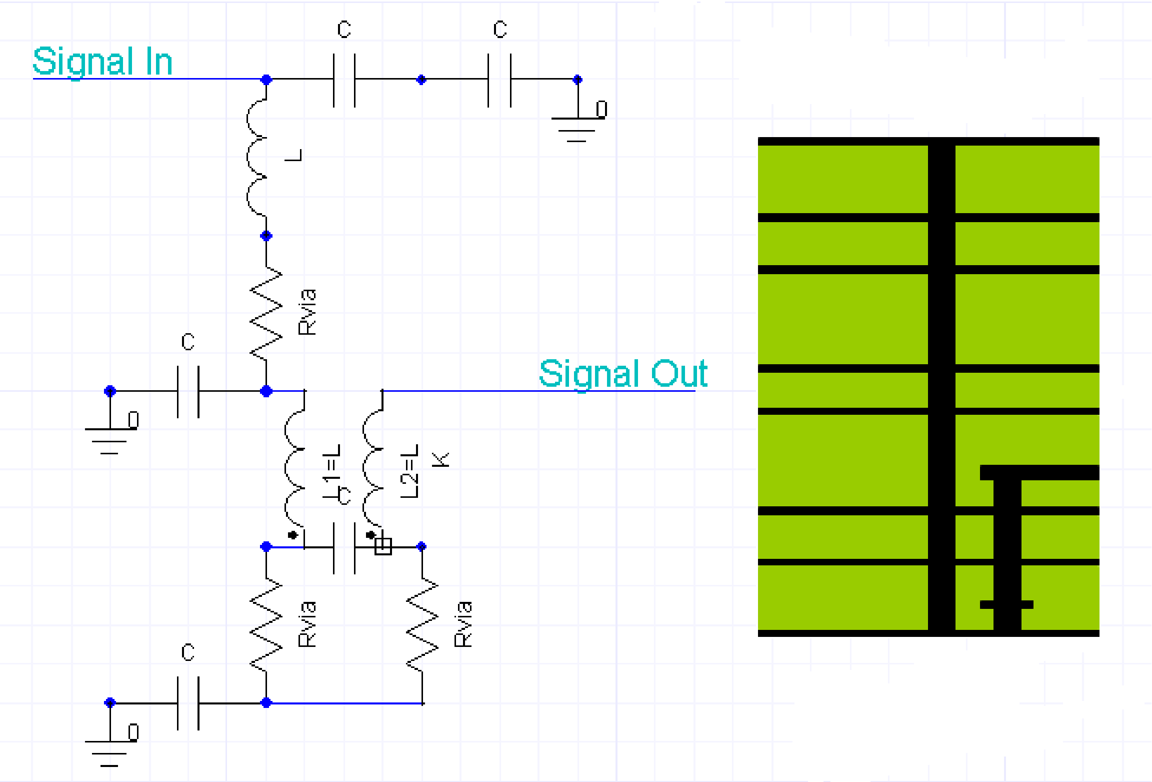


Figure 15 What NOT To Do To Reduce Via Stubs

Conclusions

Via stubs clearly degrade signals, more so with longer stubs and at higher frequencies. However, the effect is muted when signal nets are short and the effect vs. via length is quite sensitive to parasitic capacitance at the end of the via stub. In addition, reducing via stubs with multiple blind and buried vias makes the signal performance worse by introducing resonances and discontinuities. Zero stub vias on Full Z-interconnect boards have the best signal performance.

On long nets, the signal degradation due to via stubs is amplified. For via stubs 30-50 mils, on nets <=80cm, the effect below 13GHz is not significant. For those same stubs on longer nets, such as 130, 150, 170cm, the effect is large at even 5GHz. As an example, on a 16 mils wide line, length 170cm, there was a large drop in signal transmission around 5GHz. Full Z-interconnect structures showed excellent performance on all signal layers.

When designing backplanes for multi-GHz signals, via stubs can significantly degrade the signals. The problem can be reduced either by eliminating those stubs, reducing stub length or by decreasing the excess capacitance at the end of a via stub. Reducing via stubs with a complicated PTH, buried and blind via structure is not recommended, it usually makes the signal path worse. A board construction, like Full-Z interconnect, with simple via structures and zero via stubs, yields the best signal performance.

References

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2. Rowlands M. and Das R.N., “Manufacture and Characterization of a Novel Flip-Chip Package Z-interconnect Stack-up with RF Structures” *IMAPS (International Microelectronics and Advanced Packaging Society) 40th International Symposium on Microelectronics*, November, 2007.
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