Resonance Stub Effect in a Transition From a Through Via Hole to a Stripline in Multilayer PCBs

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***Abstract*—We present results of study of the resonance stub effect occurring in a transition from a through via hole to a stripline in a multilayer printed circuit board (PCB). This effect for via structures including ground vias is estimated by numerical simulations and measurements in the frequency band up to 20 GHz. Ways to alleviate problems in the design of interconnections embedded in multilayer PCBs due to the resonance stub effect and possible applications of the effect in microwave filtering are traced.**

***Index Terms*—Bandstop filters, interconnect circuits, multilayer printed circuit boards.**

I. Introduction

WITH THE rising data rate in transmission channels of high-speed digital and communication systems [1], the importance of high-frequency phenomena in interconnect circuits continues to grow as a result of their effects on performance and cost. A multilayer printed circuit board (PCB) is a type of low-cost interconnect structure which commonly includes through via holes and striplines.

Resonance effects due to a stub in a transition from a through via hole to a stripline in multilayer PCBs can significantly worsen electric performance of the transition at higher frequencies. In particular, it was indicated on this effect in [2] where differential via holes were considered and effectively modeled as a cascade of capacitances and inductances.

In our letter, we present a study of the resonance stub effect in via structures including ground vias embedded in a multilayer PCB by a three-dimensional electromagnetic field simulator [3] based on the time-domain analysis [4] and measurements at frequencies up to 20 GHz. Consideration of a signal via and ground vias as a group is urgent because ground vias are usually used to form the vertical transmission line of good wave guided properties and low radiation (leakage) losses [5], [6].

II. Transitions From a Through Via Hole to a Stripline Simulation and Measurement Results

Two types of the stub shown in Fig. 1 in signal paths from port 1 to port 2 are studied here. It can be seen that stub structures exist in both transitions from a through via hole to a stripline.

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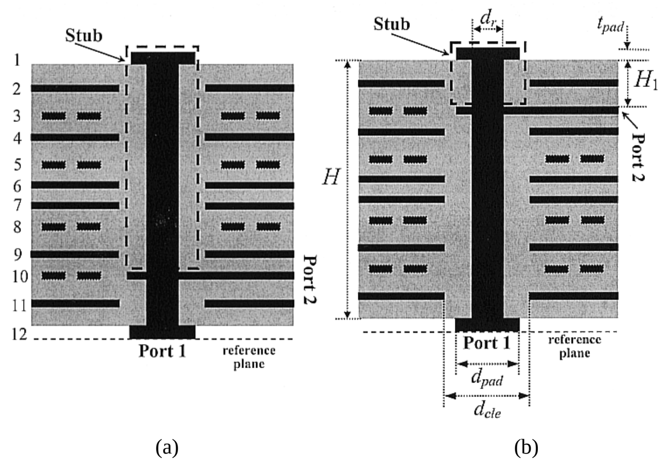

Fig. 1. Configurations of through-hole-via-to-stripline transitions at (a) tenth and (b) third conductor layers in the twelve-conductor-layer PCB.

However, being different in their lengths calls for the establishment of the resonance in the transitions at different frequencies (for the longer stub the resonance will be shifted to the lower frequencies). In this figure, the through-hole-via-to-stripline transitions using different signal paths (third and tenth conductor layers) are embedded in the twelve-conductor-layer PCB (numbering of conductor layers is shown in the figure), in which conductor layers are isolated by a dielectric material. In our computation models, the PCB has a thickness, H, of 2.4 mm, the dielectric material is assumed to be lossless with permittivity of 3.8 and conductors are considered as perfectly conducting.

At first, we show simulated characteristics of the transitions from a through via hole to a stripline (see Fig. 1) with an arrangement of ground vias demonstrated in Fig. 2 where l is the distance between vias. This via configuration corresponds to a cell of a high-density via structure under a large-scale integration (LSI) chip. The signal via-hole in the transition has a pad diameter, d_{pad}, of 0.5 mm, a pad thickness, t_{pad}, of 0.055 mm, a clearance hole diameter, d_{cle}, of 0.8 mm and a rod diameter, d_r, of 0.25 mm. Ground vias in the configuration are the same as the signal via but are connected to all ground planes. Stripline dimensions in signal paths are as follows: $w = 0.127$ mm, $h_1 = 0.23$ mm, $h_2 = 0.13$ mm and $t = 0.035$ mm. Magnitudes of the S-parameters for the configuration shown in Fig. 2 with $l = 1.0$ mm are demonstrated in Fig. 3 for short ($H_1 = 0.455$ mm) and long ($H_1 = 1.91$ mm) stubs corresponding to transitions at the third and tenth conductor layers. As follows from this figure, the stub resonance for the transition at the tenth conductor layer surrounded by ground vias occurs at 13.7 GHz. However, for the transition at the third conductor layer surrounded ground vias,

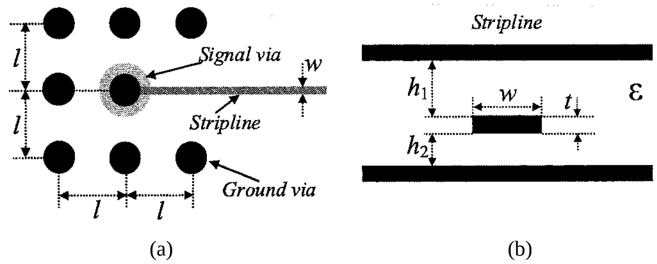

Fig. 2. Via configuration under simulations including through-hole-via-to-stripline transitions shown in Fig. 1.

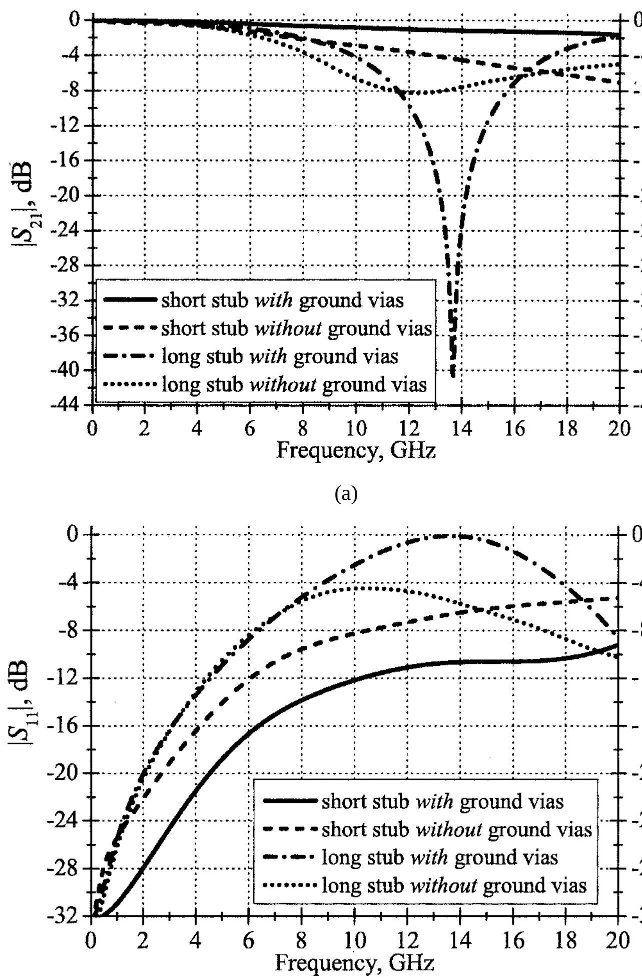

Fig. 3. Simulated insertion ($|S_{21}|$-parameter) and return ($|S_{11}|$-parameter) losses for the configuration shown in Fig. 2.

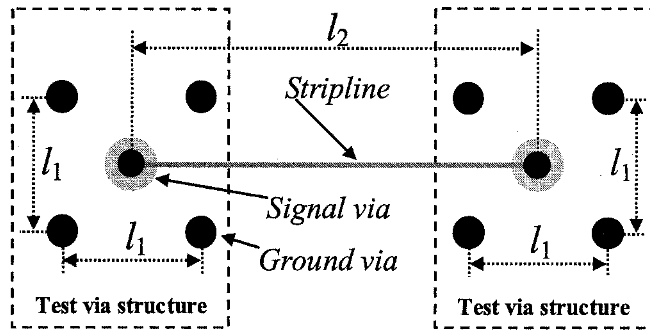

Fig. 4. Geometry of the experimental pattern with via structures under SMA connectors in the twelve-conductor-layer PCB.

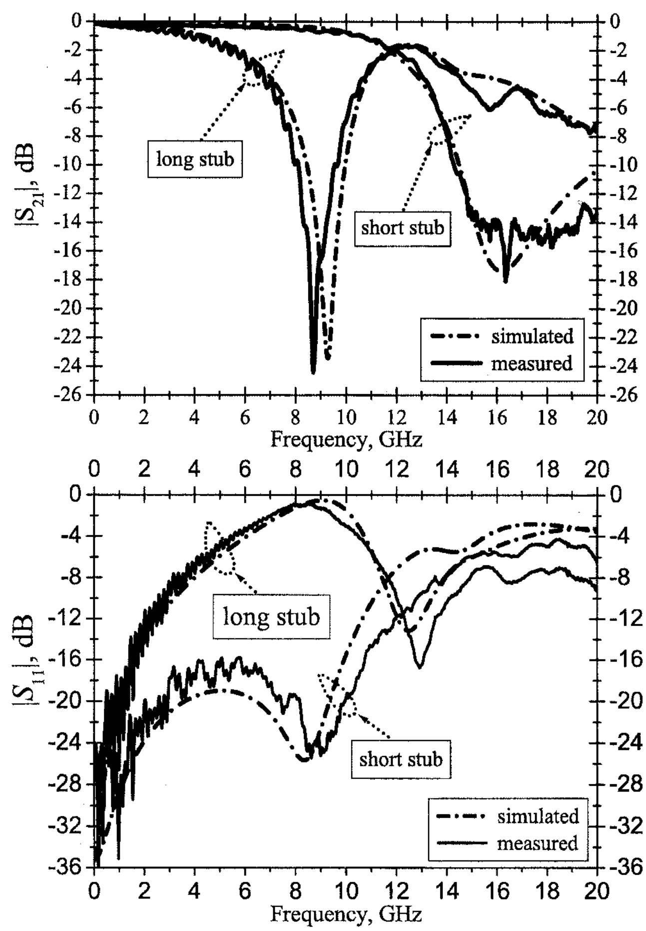

Fig. 5. Measured and simulated insertion ($|S_{21}|$-parameter) and return ($|S_{11}|$-parameter) losses for through-hole-via-to-stripline transitions at tenth (long stub) and third (short stub) conductor layers extracted from the experimental pattern shown in Fig. 4.

the such resonance frequencies are outside the considered frequency band. In the figure, the S-parameters of the signal via without ground vias for long and short stub cases in the same PCB estimated by the simulator are also demonstrated. Moreover, comparisons of presented data show that ground vias can improve the performance of through-hole-via-to-stripline transitions, but outside the stub resonance range.

Thus, on the one hand, the resonance stub effect can dramatically degrade electrical performance of high-speed interconnect circuits using the transition with a long enough stub and, on the other hand, ground vias can shape a stub resonance structure of a high-Q-factor which can be applied to develop compact band-stop filters.

To experimentally verify the aforementioned simulation results of the stub effect we present magnitudes of the S-parameters for another via configuration embedded in the same twelve-conductor-layer PCB and used under the SMA connector. The experimental PCB consisted of copper conductor layers and FR-4 material with a relative permittivity of 3.8 and loss tangent of 0.016. Shown in Fig. 4 the test pattern includes two of the identical signal vias spaced on l_2 with $d_{pad} = 1.1$ mm,

$d_{cle} = 1.6$ mm and $d_r = 0.7$ mm and connected by means of the stripline with the same cross-section dimensions as in the foregoing simulations. Each signal via is surrounded equidistantly by four ground vias connected to ground planes with $d_{pad} = 1.35$ mm and $d_r = 1.0$ mm and spaced on $l_1 = 5.08$ mm. Due to the symmetric location of conductor layers in the test PCB, the stub effect at the third and tenth signal layers was studied by placing in turn SMA connectors on the top and the bottom of the PCB. Insertion and return losses for the individual through-hole-via-to-stripline transition were determined by applying an extraction procedure [7] taking into account the identity of the two SMA connector via configurations. In the procedure, measured data obtained with an HP8510C network analyzer for two experimental patterns with stripline lengths of $l_2 = 200$ mm and $l_2 = 400$ mm were used. Note that reference planes in all measurements and simulations were at the beginning of the signal via pads (see Fig. 1). Insertion and return losses for the individual via structure shown in Fig. 4 with short and long stubs in the transition are presented in Fig. 5. Simulated and measured data in this figure are in good agreement. This is a verification of inferences from the simulation results of the stub effect. Note that the stub resonance for the SMA connector via configuration with the transition at the tenth conductor layer is exhibited at a frequency about 9.0 GHz, which is shifted to lower frequencies in contrast to the configuration in Fig. 2. In particular, it can be explained by considering effective capacitance, C and effective inductance, L, of a via stub structure and applying the known formula for resonant LC circuits as $f_{res} = 1/(2\pi\sqrt{L \cdot C})$.

Thus, the larger pad of the signal via and increased distance to ground vias, as in the case of the SMA connector via configuration, shift the resonance to lower frequencies due to the increase of effective capacitance and inductance in the stub structure. One can notice that these properties of via structures can be used to control the resonance frequency of the stub. Also, a transition from a through via hole to a stripline or a set of these transitions having effective capacitance and inductance of the stub structure as small as possible is a way to minimize the stub resonance effect in interconnect circuits at the considered frequency band.

III. Conclusion

The resonance stub effect in a transition from a through via hole to a stripline surrounded with ground vias in a multilayer PCB has been demonstrated. The main results from our study are as follows. 1) The use of ground vias offers both an improvement of the electrical performance of the transition from a through via hole to a stripline in the multilayer PCB and a shift in the stub resonance to higher frequencies, which extends the operating range of the transition. 2) Ground vias can form a stub resonance structure with a high Q-factor that is promising in the development of compact bandstop filtering components based on vertical transmission lines in multilayer PCBs.

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