Crosstalk Effects of Differential Thin-Film Microstrip Lines in Multilayer Motherboards

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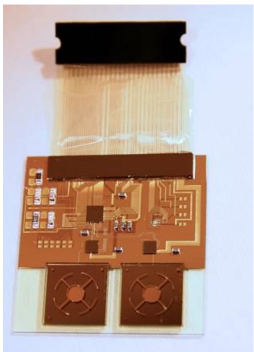
***Abstract* — With increasing demand for miniaturization the requirements for packaging and system integration are more challenging especially when more and more components are to be integrated into a compact module. In such a situation, crosstalk effects and signal degradation due to dense layouts may become critical. The focus of this paper is on the influence of neighboring elements, discontinuities and ground layer modifications in coupled thin-film microstrip lines in differential operation. Moreover, design guidelines how to mitigate these effects are provided.**

***Keywords* — crosstalk effects, discontinuities, microstrip.**

I. Introduction

With increasing demand for miniaturization, high-density layouts are inevitable and line routing becomes a critical task, ensuring minimum size of a module without perturbing the performance. In motherboards (e.g. Fig. 1 left) whose layouts are filled with a high amount of interconnects and integrated components parasitic effects may arise due to crosstalk effects and become an issue. In [1] the electromagnetic impact of discontinuities in coupled microstrip lines has been investigated. In [2] crosstalk effects for differential lines are studied. However, these investigations are limited to 24 GHz or below.



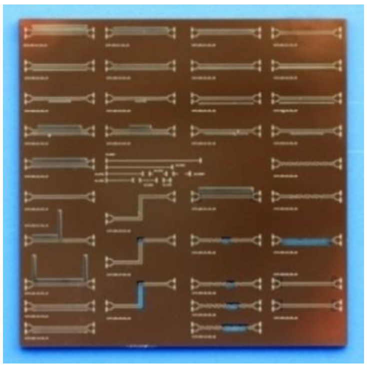


Fig. 1. Example of a miniaturized motherboard with flip chip integrated components (left); Test platform manufactured for investigations (right).

In this paper, we extend the frequency range up to 110 GHz and study different crosstalk effects for differential lines. Fig. 2 presents a zoomed view of the motherboard without the integrated chips showing the investigated radiofrequency (RF) lines.

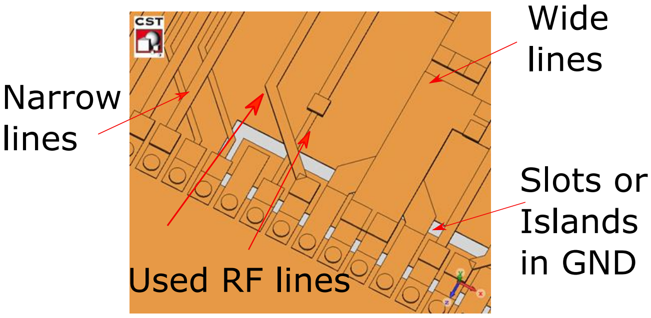


Fig. 2. Zoomed view of a miniaturized motherboard (graphics shown in CST Microwave Studio).

The differential lines consist of two microstrips (in a distance of 163 µm), excited in differential operation. The distance to substrate thickness ratio is relatively large (10.2), as is common for such differential lines. They are surrounded by different neighboring structures of varying shape, length, width and terminations.

In most applications, the dimensions of the neighboring structures are predefined and cannot be changed during layout. For allowing the line routing in different layers due to the high amount of interconnects, ground (GND) modifications, e.g., slots and openings, are unavoidable. Therefore, a superposition of different parasitic effects may arise due to:

- Neighboring structures of different shape
- Discontinuities and bends
- GND modifications, e.g., slots and openings

To understand the impact of these effects, a test platform (Fig. 1 right) has been designed, manufactured and characterized by measurements and electromagnetic (EM) simulations using CST Microwave Studio [3]. The designed wafer (Fig. 1 right) emulates the line routing of the miniaturized motherboard (Fig. 2) and is implemented in a thin-film multilayer stack which is realized on top of a 700 µm thick borofloat substrate. The signal layer is placed on top of the benzocyclobutene (BCB) and the GND layer is buried in the 16 µm thick BCB layer stack. This process was developed at FhG IZM as motherboard for microwave modules.

II. Validation of the Reference Structure

The basic structure for comparison (Fig. 3) is a configuration of two parallel 50 Ω lines with a signal conductor width of 37 µm. The parallel lines are 5000 µm long and placed in a distance of 163 µm for emulating the described case (Fig. 2). To allow for on-wafer probing a special pad configuration including a coplanar waveguide to microstrip (CPW-to-MS) transition is designed.

Fig. 3. Basic structure for comparison with the ports A,B,C and D.

The measured and simulated data is calibrated applying the multiline Thru Reflect Line (mTRL) calibration [4]. In simulation, a detailed probe model is used for excitation and compared to a bridge model (see Fig. 4) [5]. Only 2-port measurements are performed, hence the Device under Test (DUT) (Fig. 3) is measured along the signal path from port A to B or from port C to D with open terminations at the ports C and D or A and B, respectively.

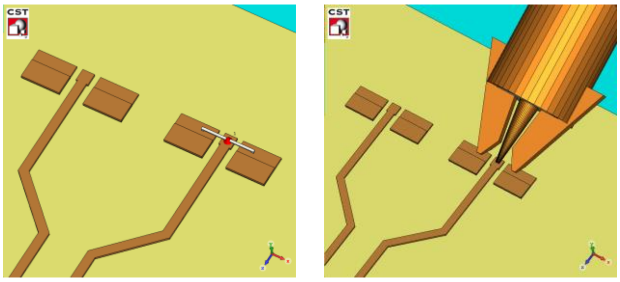


Fig. 4. Different excitation; left: bridge model; right : probe model.

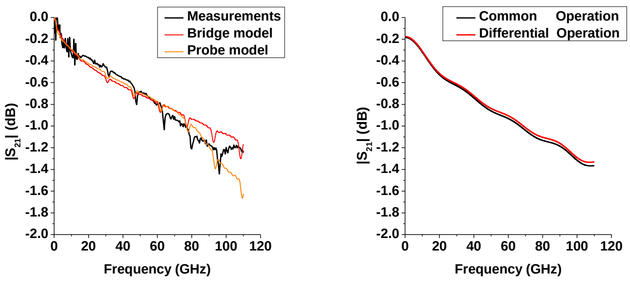


Fig. 5. Left: Measured and simulated S_{21} from C to D; right: Calculated transmission coefficient of the DUT in common and differential operation.

Overall, there is a good agreement between the simulated data with both excitations and the measured results (Fig. 5 left). The origin of the dips can be traced back to the fact that the ports of A and B are open-ended and not terminated with 50 Ω resulting in a resonance behavior due to half-wavelength resonances of the 5 mm long coupling line. The transmission coefficients of the common and differential signals are determined applying the formula of [6] with all the ports terminated with 50 Ω (for the bridge excitation) and plotted in Fig. 5 right. One finds smooth curve behavior for both modes and the ripples in the single-ended measurements (Fig. 5 left) disappear because the ports of the coupled line are now matched with 50 Ω. The insertion loss of the DUT in differential and common operation remains below 1.5 dB up to 110 GHz. This represents the ideal case of a DUT without perturbations by any neighboring structure.

In the following sections, all DUT results presented refer to the calculated transmission coefficients [6] obtained from simulations using the bridge model. The simulation data was validated by measurements and good agreement was found.

III. Impact of Neighborhood

In a compact layout parallel line routing of differential lines is inevitable (Fig. 2). The question now is whether and how the transmission of the investigated DUTs in common and differential operation is affected when neighbors are present.

A. Impact of Distance between DUT and Neighbors

In the following, the influence of neighbors is investigated by adding a sideway neighbor to the reference structure (Fig. 6) and then varying the distance d between the sideway neighbor and the measured DUT. The sideway neighbor is intentionally placed parallel to the homogeneous part of the differential lines to avoid probe coupling (Fig. 6).

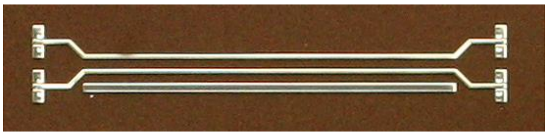


Fig. 6. DUT with neighboring structure.

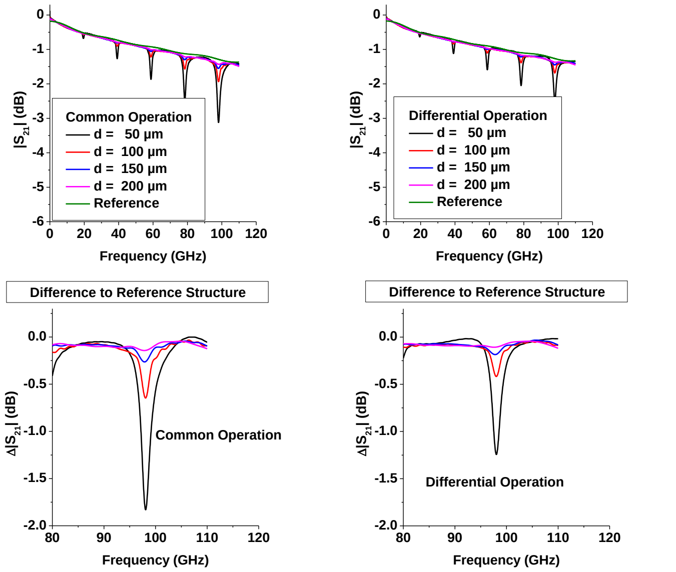


Fig. 7. Simulated transmission coefficient of DUT in common operation (left) and differential operation (right) when varying the distance d.

Obviously, with larger distance the dips for the common and differential operations (Fig. 7) become weaker and finally fade away due to the lower coupling (see Fig. 8). Applying a distance of approximately 150 µm (ten times the substrate thickness) results in a reduced dip behavior with $\Delta S_{21} < 0.3$ dB for both common and differential operations up to 110 GHz.

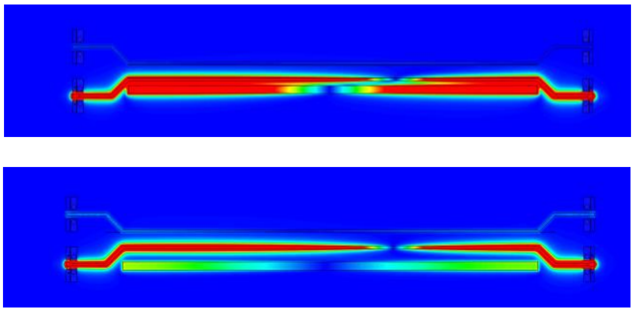


Fig. 8. Color-coded electric field magnitude at f = 20 GHz for top: DUT with distance of d = 50 µm; bottom: DUT with larger distance of d = 150 µm.

B. *Additional Neighbor with Different Width*

In a compact layout, the structures are normally not surrounded by only one neighbor; there is a high amount of different combinations of adjacent structures. The shape, width, and length of the neighbors can also vary.

Fig. 9. DUT with 2 neighboring structures of different width.

Fig. 9 illustrates one possible combination in which the measured DUT is surrounded by a neighbor with a larger width of 300 µm on one side and a neighbor with a smaller width of 100 µm on the other side. Both neighbors are placed at a distance of 100 µm to the measured DUT and have the same length of 5000 µm.

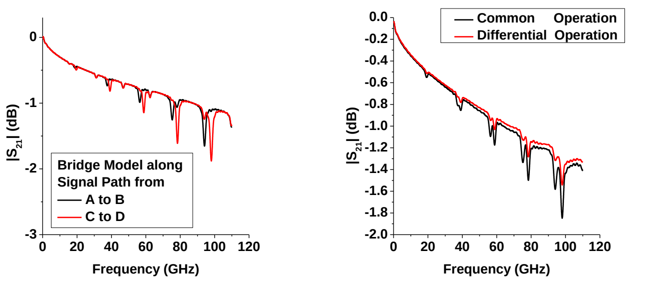


Fig. 10. left: Simulated transmission results along the signal path from A to B and C to D. Right: Calculated transmission coefficient of the DUT in common and differential operation.

The results are presented in Fig. 10. The curves indicate that larger width of the neighbored microstrip changes the strength of the dips and reduces the dip frequency. This behaviour can be attributed to the increase of the effective permittivity of the neighbored microstrip lines, which reduces the resonant frequency. The increase of the effective permittivity can be explained by the fact that the electric fields are more concentrated in the substrate for a neighboring structure with larger width compared to that with smaller width (see Fig. 11). Therefore, when designing a compact layout, it is essential to understand to what extent the impact of the neighboring structures including their shape, width, length and the distance between the DUT and its neighbor can contribute to parasitic effects of the measured DUT in both common and differential operations.

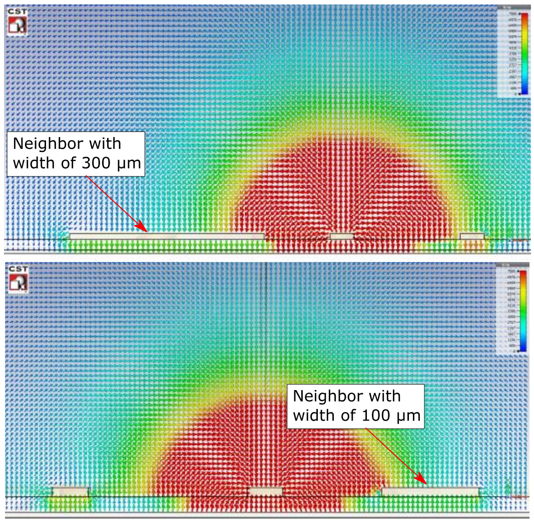


Fig. 11. Electric field plots for top: DUT with a neighbor of 300 µm width and bottom: DUT with a neighbor of 100 µm width (scaling adapted to emphasize coupling effects).

Further investigations reveal that the length of the neighboring structures mainly determines the position of resonance frequency, the width both the resonance frequency and the strength of the dips in the transmission curve, whereas the distance between the DUT and neighboring structures only affects the strength of the dips.

IV. Impact of Discontinuities

Geometrical discontinuities in layouts (e.g. bends, displacements between the differential lines, perturbations in the GND layer) are unavoidable for line routing. Some of them are investigated in the following subsections.

A. *Impact of Slots underneath Bends*

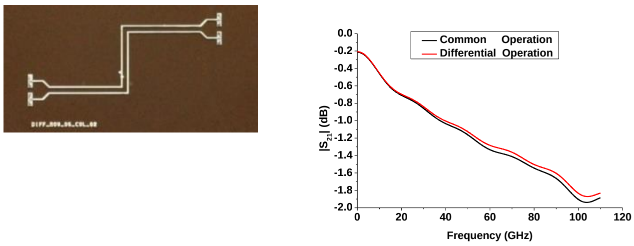


Fig. 12. left: DUT with two bends; right: Calculated transmission coefficient of the DUT in common and differential operation.

Fig. 12 left illustrates a DUT with two counter-rotating bends (as reference to further investigations). The results in Fig. 12 right show that the curve behavior of the DUT in common and differential operation is not strongly affected by the introduction of the bends. In many applications, slots in GND are implemented [7] in differential lines, especially for the suppression of the common mode [8] since the electric fields of the common mode will be significantly distorted through the absence of the GND. Here, two cases are investigated; case A and case B. For the asymmetric case A, a square area in the GND directly underneath the bend is opened, whereas in the symmetric case B a rectangular area extending to the second bend is opened in the GND.

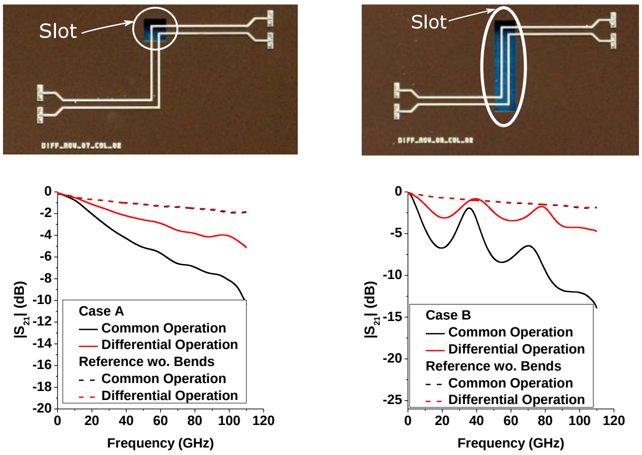


Fig. 13. Calculated transmission coefficient of DUT in differential and common operation for left : Case A; right: Case B.

The results in Fig. 13 reveal that introducing slots in the GND are not very helpful to suppress propagation of the common mode in our case. Moreover, the differential mode is also degraded, especially beyond 12 GHz, since due to the relative wide separation there are significant GND currents below the strips.

B. Combination of GND Opening with Neighbors

Fig. 14. DUT with modified GND construction and a wide neighbor.

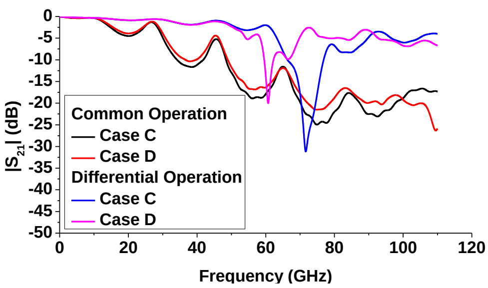


Fig. 15. Calculated transmission of DUT in common and differential operation.

Here, we investigate a special GND modification (see Fig. 2). Additionally neighboring structures are closely placed next to the DUT (see Fig. 2). Therefore, two cases are investigated; a modified GND layout denoted as case C implementing symmetric islands and case D adding a neighbor beside the differential lines (see Fig. 14). The results in Fig. 15 reveal how islands in the GND together with the effect of neighbors deteriorate the performance of DUT in common and differential operation. Thus, in practical applications openings and islands in GND should be avoided, at least if the differential lines are realized with a large distance-to-substrate thickness ratio (about 10 in our case).

V. Conclusion

The results presented illustrate in which way neighboring structures, bends and GND openings in differential thin-film microstrip lines can contribute parasitic effects and signal degradation. Summarizing the results, one should apply a minimum distance of ten times the substrate thickness of the thin-film microstrip line to mitigate parasitic coupling to neighboring structures and any GND modification such as openings or islands should be avoided as far as possible.

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