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EM Parametric Study of Length Matching Elements Exploiting an ANSYS HFSS Matlab-Python Driver

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***Abstract* — This work presents a Python-based driver for ANSYS HFSS for length matching elements (LME) implemented in Matlab. The driver allows full-wave EM parametric simulation of length matching elements, whose S-parameters are inserted in other circuit simulators, such as ADS, for a complete interconnect validation. Three different LME (i.e., trapezoidal, triangular, and rectangular) are analyzed using the driver in a common high-speed routing scenario. The driver proposed in this work allows verifying that the three LME considered have a similar performance up to 5 GHz, indicating that these LME can be used as mismatch (phase skew) compensation structures in some interfaces within this frequency band, such as USB 3.0, PCIe Gen3 or 1 GBASE Ethernet. On the other hand, the trapezoidal LME shows the best performance for frequencies higher than 5 GHz, with a low impact in the electromagnetic interference (EMI), making it the most recommended for high-speed interfaces with operating frequencies higher than 5 GHz.**

***Index Terms* — ADS, differential interconnects, full-wave EM simulation, HFSS, length matching elements, Matlab, mode conversion, TDR, Python, S-parameters**

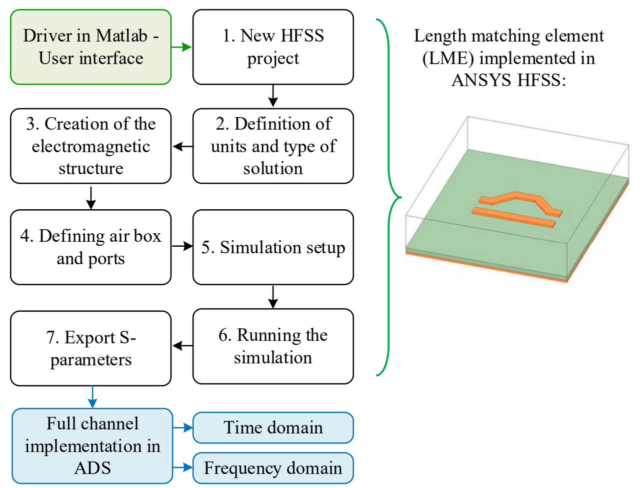

Fig. 1. Flow diagram of the driver and a length matching element (LME) implemented in ANSYS HFSS.

I. Introduction

The homogeneous routing of edge-coupled transmission lines is a challenge in high-speed PCBs implementations. Transitions, such as vias and bends, are unavoidable in typical PCB designs, impacting the performance of high-speed channels [1]. A common strategy to compensate the mismatch caused by bends in edge-coupled interconnects consists of using length compensation elements (LME). The traces mismatch, which yields phase skew, is physically compensated by changes in the routing forming the differential channel [2].

Different options for length matching elements have been proposed. The trapezoidal shape allows a good channel performance, reducing insertion and return losses [3], however, their implementation can be difficult in dense routing areas (e.g., close to the pinout). Serpentine shapes show a similar performance [4], however, their physical area for implementation is even larger and more problematic.

This paper presents a Python-based driver to create LME in individual cells for usage in complex high-speed interconnects. The driver allows the user to create a setup environment in ANSYS HFSS[1], using Matlab[2] as user interface. The user only introduces the LME design parameters and the tool returns the corresponding S-parameters, which are later inserted in ADS for simulation of the complete routing scenario. The driver allows parameterized implementation of three LME (i.e., trapezoidal, triangular, and rectangular shapes) to compensate a mismatched channel implemented in ADS[3]. Our study case shows that the trapezoidal LME has the best performance up to 15 GHz, however, the triangular and rectangular shapes, which are easier to implement, exhibit a similar performance up to 5 GHz, which makes them suitable for high-speed interfaces in this frequency frame, including USB 3.0, PCIe Gen3 or 1 GBASE Ethernet.

II. Driver Implementation

Our Python script for the driver is created from Matlab. The user introduces design parameters of the desired structure and the code automatically generates the setup environment and simulate it in ANSYS HFSS. The script is structured in 7 steps (see Fig. 1). The first step is the creation of a new HFSS project; here, the script opens the ANSYS Electronic desktop and creates the ANSYS HFSS project. The second step is to

[1] ANSYS HFSS 2018, Release 18, ANSYS Electromagnetics Suite, 2016.
[2] MATLAB, Version 9.3.0, The MathWorks, Inc., 3 Apple Hill Drive, Natick MA 01760-2098, 20017.
[3] Keysight Advanced Design System (ADS) 2016.01, 5301 Stevens Creek Boulevard, Santa Clara CA.

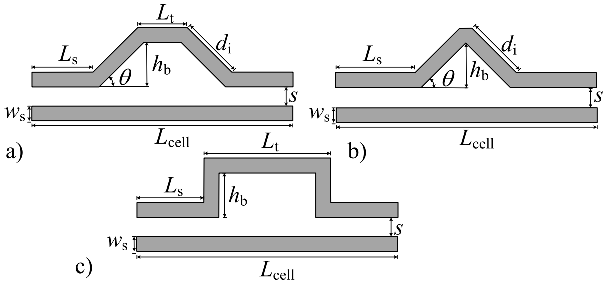

Fig. 2 Length matching elements (LME) for differential interconnects: a) trapezoidal, b) triangular, and c) rectangular.

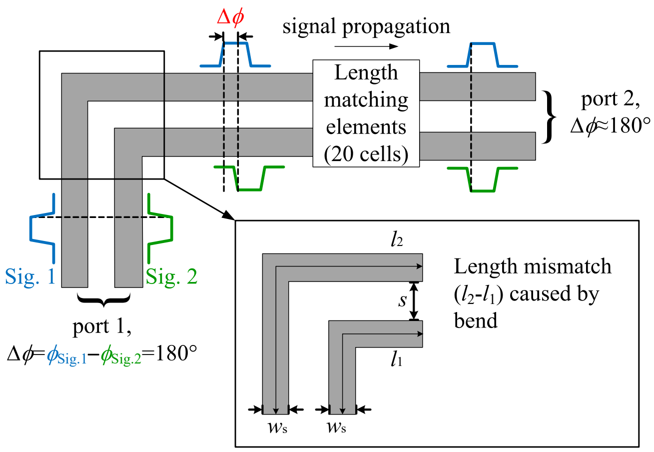

Fig. 3. Mismatch (phase skew) caused by a right-angle bend and its compensation using length matching elements (LME).

define the units and the solution type in HFSS. The terminal solution is selected and applied to a cell; each cell contains an LME and its ports. The third step is the creation of the LME itself, which is created based on the parameters defined by the user on the Matlab interface. Fig. 2 shows the LME that can be created with the proposed driver. Notice that the triangular, rectangular, and the homogeneous transmission line can be created by only changing the parameters θ and L_t (i.e., rectangular θ = 90º, triangular θ < 90º and L_t = 0 mils). The fourth step allows defining the airbox and the ports. The fifth step is the simulation setup; here, the user can select the initial and final frequency, and the steps for single and multi-frequencies, etc. The sixth step is to validate and run the simulation, and finally, the seventh step is to export the S-parameters; in this step, the user can select the folder where the S-parameters are saved. The final simulation of the complete channel or routing scenario is performed in ADS to estimate its performance in frequency and time domains.

III. Study Case

The effectiveness of the length matching elements implemented with the driver is evaluated by compensating an edge-coupled transmission line in a usual routing scenario. Fig. 3 shows a typical case, where a 90° bend produces a mismatch between the traces forming the edge-coupled transmission line. The signals in port 1 have a phase difference of $\Delta\phi$ = 180º, but once these signals propagate along the right angle bend, a skew is observed and the phase difference changes ($\Delta\phi \neq$ 180º). The length mismatch is compensated by introducing the length matching elements to the shorter trace after the curve. These structures produce delays in the signal traveling along the shorter trace that reduce the phase difference, making it close to 180º ($\Delta\phi \approx$ 180º) in port 2.

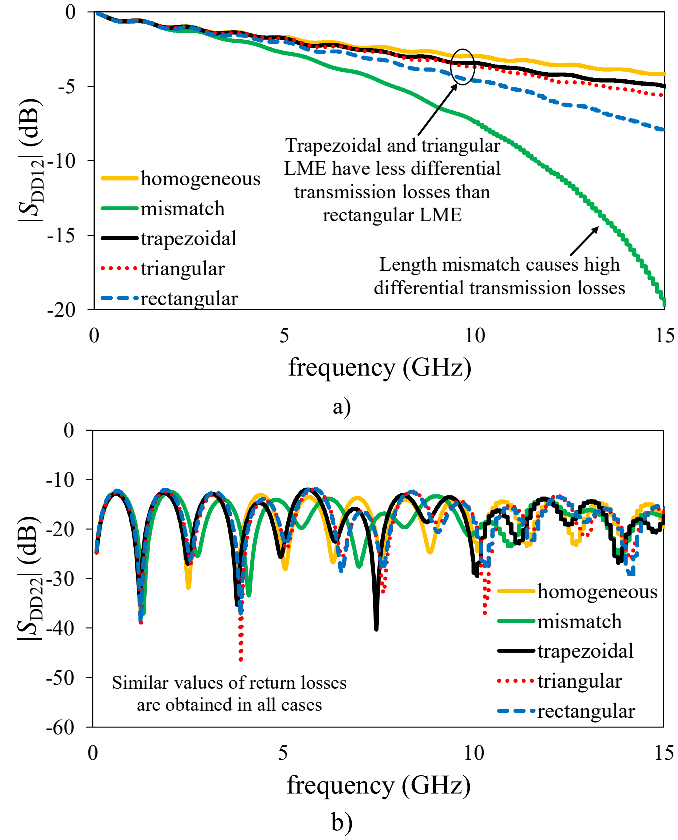

Fig. 4. Differential S-parameters of the length matching elements considered: a) insertion loss, and b) return loss.

The edge-coupled microstrip transmission line has the following design parameters: the characteristic impedance is Z = 80 Ω, the trace's width is w = 6.6 mils, the dielectric thickness is h = 3 mils, the spacing is s = 8 mils, the length is l = 2,600 mils and the width of the ground plane is w_g = 10h. The substrate has a relative dielectric permittivity ε_r = 4.2 and a loss tangent tan(δ) = 0.02; the metal layers are copper with a conductivity σ = 5.7×10^7 S/m and thickness t = 1.5 mils. The mismatch introduced by the right angle bend is 200 mils and it is placed 1,300 mils apart from port 1.

As mentioned before, three LME cells are implemented using our driver. The trapezoidal structure (see Fig. 2a) uses L_t = 15 mils, L_s = 8 mils, h_b = 12.25 mils, d_i = 17.75 mils, and θ = 45º. The triangular structure (see Fig. 2b) uses d_i = 19 mils, L_s = 13.5 mils, and θ = 45º. The rectangular structure (see Fig. 2c) uses L_s = 13 mils, L_t = 6 mils, h_b = 27 mils, and θ = 90º. These cells are then used to compensate the study case, where 20 cells of the same structure, implemented in ADS, are designed to compensate 10 mils of mismatch each. Since the

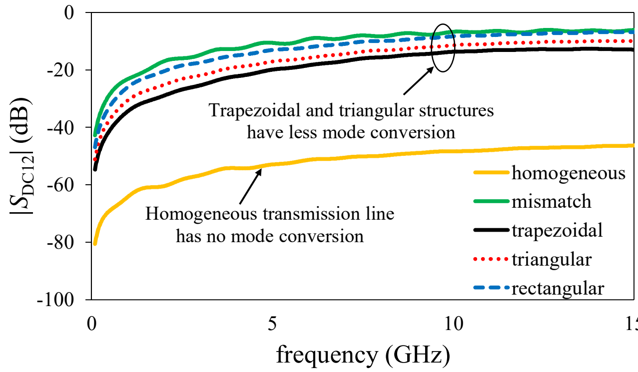

Fig. 5. Differential to common mode S-parameters (mode conversion) caused by the length matching elements.

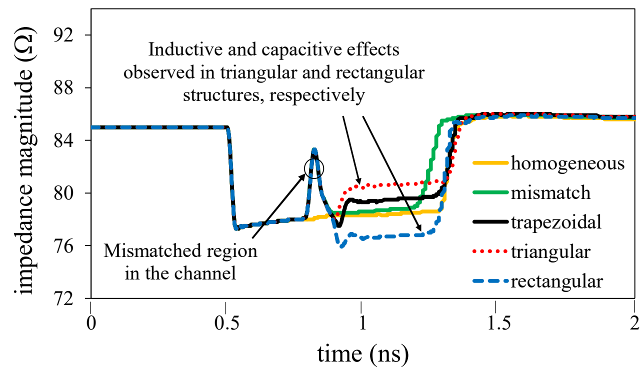

Fig. 6. TDR of the structures analyzed in this work.

cell's length is L_{cell} = 55 mils, the 20 cells have a total length of 1,100 mils.

IV. Results and Comparison

The S-parameters of the full channel described in Section III, obtained from ADS, are further analyzed extracting the mixed mode parameters [5]. These parameters give information about the differential channel insertion loss (S_{DD12}), the return loss (S_{DD22}), and the mode conversion (S_{DC12}). Fig. 4 and 5 present a comparison of four different cases: the transmission line described in Section III with no mismatch ("homogenous"), with a 90° bend but without any compensation ("mismatch"), with a 90° bend and compensated with trapezoidal LME structures ("trapezoidal"), with a 90° bend and compensated with triangular LME structures ("triangular"), and with a 90° bend and compensated with rectangular LME structures ("rectangular").

Notice that all cases with length matching elements (LME) have a similar insertion loss up to 5 GHz (Fig 4a). Once the frequency increases, the difference between the curves increase, particularly the trapezoidal and triangular shapes present fewer insertion losses than the rectangular shape, and they are closer to the homogeneous case. The non-compensated transmission line (mismatch) presents the highest insertion loss, as expected. These results confirm that utilizing LME compensation significantly reduces losses in the channel. As for the return losses (Fig. 4b), they are also similar for frequencies below 5 GHz, however, as the frequency increases, the difference between the curves grow and other undesired effects are observed in the highest frequency range.

The conversion mode parameters, shown in Fig. 5, show that lower radiation is obtained when the trapezoidal shape is used to compensate the differential channel. However, the triangular shape presents a competitive performance to that one of the trapezoidal case. In contrast, the performance of the rectangular shape is poorer and too close to the mismatch case in the high frequency range.

Finally, Fig. 6 presents an analysis of the transient impedance profile, from 0.5 ns to 1.4 ns. Notice that all cases have the same impedance until the signal crosses the 90° bend at 0.8 ns. In that instant, impedance increases to about 83 Ω. After 0.9 ns, the LME cells influence the impedance profile. Notice that impedance in the rectangular LMEs is lower than the homogeneous case (around ~78 Ω); this is due to the high capacitive effect induced by its shape (since it has 90° sections that increase the electric field intensity between the trace and the ground plane). On the other hand, smoother LMEs such as trapezoidal and triangular shapes, present good performance in impedance profile, reducing capacitive effects. However, the triangular structure presents a higher impedance due to the longer distance between the internal section and the parallel trace than that one of the trapezoidal shape.

V. Conclusion

In this work, an EM-based performance comparative study of mismatch compensation structures for differential interconnects was presented. The study makes use of a proposed Matlab-Python driver for ANSYS HFSS. The results showed that for frequencies up to 5 GHz, all the compensating structures considered have similar performance in insertion and return losses. However, higher radiation is observed for rectangular structures. Therefore, applications in this frequency range with low EMI requirements can use simpler structures to compensate for the mismatch than classical trapezoidal or serpentine structures.

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