

# Efficient Methodology for Modeling Structure of High-Speed Long Transmission Lines

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**Abstract**—A practical approach for accurately modeling high-speed link structures is presented and named as the “cut and stitch” (C&S) methodology. To generate S-parameters for the whole system, C&S first cuts the structure into different parts with different electromagnetic (EM) features and also provides auto-generated ports at the cutting interfaces to do system connection later, then selects the proper EM solver for individual design partition’s modeling, and finally automatically stitches all of the S-parameter models together. Numerical experiments show that the approach can achieve more than one order of the speedup ratio with the acceptable accuracy.

**Keywords**—C&S; signal integrity(SI), hybrid EM solver.

## I. INTRODUCTION

In a real board design system, the typical signal trace routing usually starts from a footprint of a component/chip, where there is not enough space for traces to be fanned out, so that they need to change to another metal layer by adding via holes. After the traces are fanned out of a component, they are kept routing on the same metal layer until they reach another component. Then the similar design situation happens again at the other end of the system, where 2D traces are gathered together under the component/chip footprint area through 3D via and other 3D/2D transitions. Sometimes, the transmission lines section in the signal link channel may be longer (>200mm) and the SI analysis needs to model up to 25GHz and higher. Using a 3D full-wave EM solver [1][2] while considering the whole structure into simulation can, of course, generate a very accurate model, however it also imposes many modeling challenges. Like high-capacity designs, it usually takes weeks of simulation time and at same time requires huge amounts of memory. On the other hand, one knows that traces routed uniformly on a metal layer with good reference plane can be modeled by 2D transmission-line hybrid solver[3] with significantly reduced simulation efforts. By carefully exploring the signal paths’ EM feature, one can generally summarize that the signal path may experience 3D to 2D to 3D transition several times. This observation motivates us to do a hybrid solution for modeling the whole long signal link system. To speed up the simulation, a 3D EM solver is only applied to places where there is via and other 3D transition at both ends to guarantee the model accuracy; while a 2D EM solver will be applied at the middle sections. Exploiting the signal path’s EM nature, dividing the whole structure into partitions, and then

using proper EM solvers to generate models, usually takes a lot of engineering effort and is error prone. Also the cutting compensation[4] at the cutting interface has drawn a lot of attention and effort. Therefore, it is of paramount importance to study and develop an automatic cut and stitch (C&S) flow to do the job automatically.

## II. CUT AND STITCH FLOW

### A. Typical Long Structure and Its Cut

Figure 1 shows a typical signal link structure with its cut.

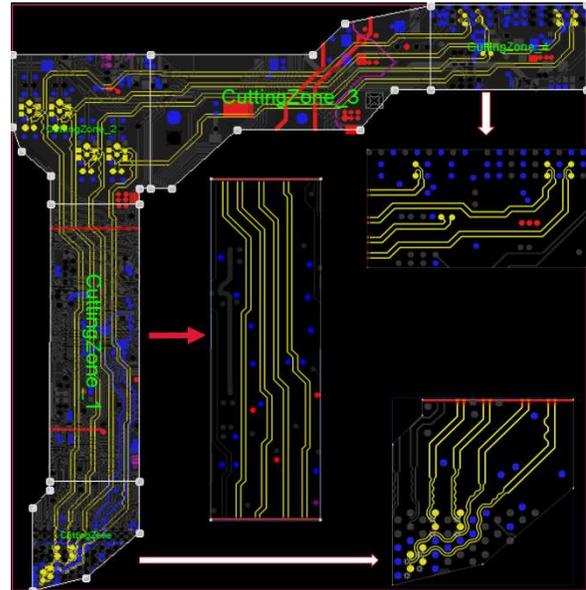


Fig.1 Long structure with eight signal paths and five cut zones.

In this signal link system, the low-left corner is a chip, the upper-right corner is another component, and there are eight signal channels connecting both components. It is divided into five sub-zones in the C&S flow. The figure shows the signal 3D transition frame in the third subpart (CuttingZone\_2). It is natural to choose the two end sub-parts and the middle transition part as the 3D EM solver zones, while the cuttingZone\_1 and cuttingZone\_3 (shown in figure1) as the 2D solver applications.

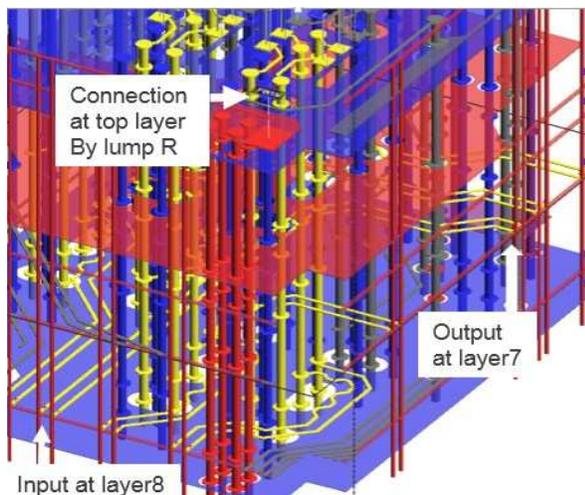


Fig.2 3D signal transition of CuttingZone\_2: Signal input from layer8 travels through the via to the top layer; through connection R; then through the via down to layer7 to output.

Great details (like TDR analysis) are paid to eliminate the cutting impacts by adding shaping and via to form a good  $\delta$ -gap impressed-field excitation[5][6] at the port as shown in figure 3. Also the SOC[4] and waveport calibration efforts are made to eliminate the cutting impacts.

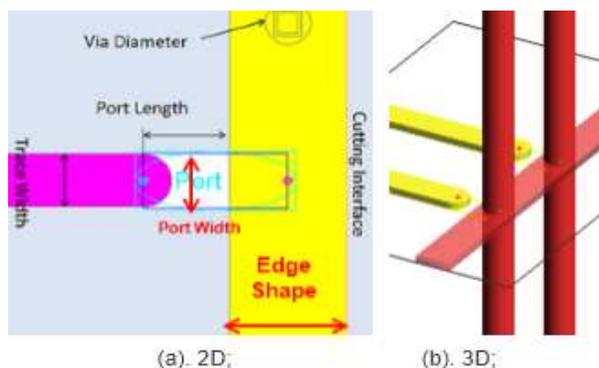


Fig.3 Port forming at the cutting interface.

### B. Stitch All the Sub-Models Together

The signal flow graph concept [7] is used to stitch all of the sub-part's S-parameters together into a final S-parameter file. This file is realized by an auto-generate circuit network topology aide file shown in figure 4. As a SPICE format circuit simulation file, the final Touchstone SNP file is formed by five modules and a cascade frame, as shown in figure 5.

### C. C&S Flow Implementation

The flow is made to do all the above steps automatically to save the users effort and to achieve good accuracy. Also automatically generated TCL script commands are provided for the advanced users to do it in a more flexible way. The flow can be summarized as following steps: (1) After loading the layouts, a user can pick up the interesting signal nets and neighbors with the aide of the GUI wizard. (2) Use the chosen signal nets geometry union with GUI-specified margin to

automatically generate the polygon that encloses the interesting calculation area, and eliminate the layout outside of the polygon. (3) Generate ports at two ends of the signal links with the aide of port wizard. (4) Cut the polygon at the appropriate location by drawing straight lines with the GUI. (5) Specify which EM solver type (2D/3D) that you will use for each subzone. (6) Click the "play" button to execute domain cutting, port generation at the cutting interface with best practical default setup to minimize the cutting impact, simulating each sub-zone with the predefined EM solver setup, stitching parts together, and finally forming the results for the whole interesting domain. It is worth mentioning that the flow can automatically send each subzone's modeling tasks to different computers to do parallel work and also can reuse the subzone's previous results to avoid redundant calculation.

```
.SP lin 100 10 MHz 30 GHz
x_ckt 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 0 ckttop
.subckt ckttop p1 p2 p3 p4 p5 p6 p7 p8 p9 p10 p11 p12 p13 p14 p15 p16 r
S1 p1 p2 p3 p4 p5 p6 p7 p8 i1 i2 i3 i4 i5 i6 i7 i8 r FML=CZ_1.S16P
S2 i1 i2 i3 i4 i5 i6 i7 i8 j1 j2 j3 j4 j5 j6 j7 j8 r FML=CZ_1.S16P
S3 j1 j2 j3 j4 j5 j6 j7 j8 k1 k2 k3 k4 k5 k6 k7 k8 r FML=CZ_2.S16P
S4 k1 k2 k3 k4 k5 k6 k7 k8 l1 l2 l3 l4 l5 l6 l7 l8 r FML=CZ_3.S16P
S5 p9 p10 p11 p12 p13 p14 p15 p16 l1 l2 l3 l4 l5 l6 l7 l8 r FML=CZ_4.S16P
.ends ckttop
```

Fig. 4 S-parameter stitch aide file.

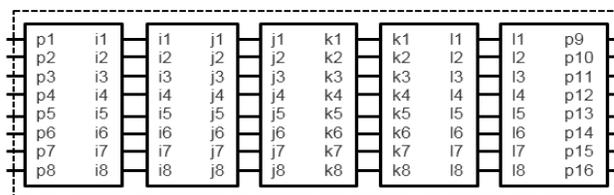


Fig. 5 S-parameters cascade frame.

## III. NUMERICAL EXPERIMENTS

Many real cases are studied and the flow's efficiency are fully explored and demonstrated. Due to the scale of this paper, we will only discuss two examples. The first one is for the structure shown in Fig.1. It is a partial board design with 11 layers. The size is big at 220mm\*220mm. Eight signal channels are studied simultaneously. Using a 3D FEM solver for the whole structure, it takes 14 days 10 hours with peak memory of 320Gb to obtain the S-parameters up to 30GHz. While using the C&S flow, "CuttingZone" is the first subzone and is done by 3D EM solver for four hours with peak memory of 23Gb; the third subzone (CuttingZone\_2) is done by 3D EM solver for 15 hours with peak memory of 47Gb; the fifth subzone (CuttingZone\_4) is done by 3D EM solver for seven hours with peak memory of 32Gb; the second (CuttingZone\_1) and the fourth (CuttingZone\_3) subzones are done by 2D EM solver within few minutes only. The final stitch takes no noticed time. Because we automatically assigned the first, third and fifth parts to different computers, the total time we used for the C&S flow is within 15.5 hours. Therefore the speedup ratio is about  $(14*24+10)/15.5=22.32$  times. While the accuracy comparison for all  $S_{ij}$  are acceptable. Fig.6 just shows one of the signal paths' S11 and S19. For the reflection loss (S11) below the 10GHz, the comparison is very good; from 10GHz to 30GHz, the form and variation of the reflection loss between the two flows are still in a good correlative way. On the other

hand, for the insertion loss (S19), the comparison between the two flows are very good through all the frequency range from DC to 30GHz.

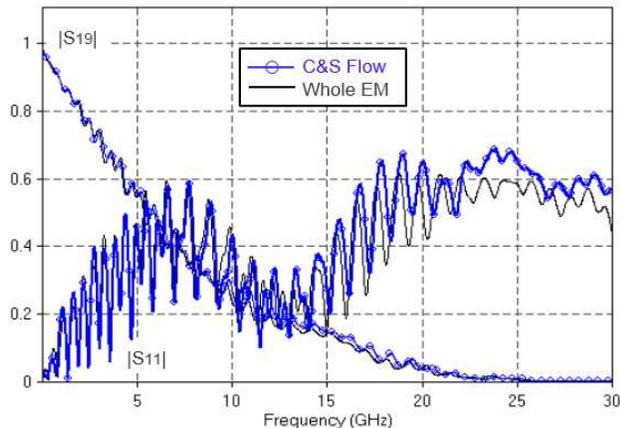


Fig.6 Comparison of the S-parameters between the two flows for structure shown in figure 1.

The second case shared here is the structure shown in figure 7 in which the transmission line is not so long (whole size is 25mm\*13mm). However, we want to demonstrate that the C&S flow also can provide a lot of help for a case like this. The package has 13 layers. The domain is cutting into three zones with the two ends solved by the 3D EM solver and a large middle section solved by 2D EM solver. If using 3D FEM solver for the whole structure, it takes 24.8 hours to obtain the S-parameters. While using the C&S flow, you can get results within 2.16 hours for a speedup ratio of 24.8/2.16=11.5. The accuracy comparison for S11 is shown in the figure 8. For the reflection loss below the 10GHz, the comparison is very good; from 10GHz to 20GHz, it is still doable.

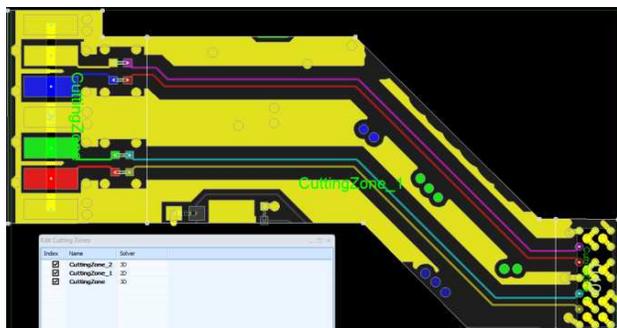


Fig.7 Medium-size structure with four signal paths and a cut.

#### IV. CONCLUSIONS

SI analysis for the high-speed linked system design is a must and is very challenging due to the high capacity. In this paper, we try to enclose the interesting signal channel zone into a polygon area to reduce the problem size first. We further reduce the problem size by dividing the domain into several

parts according to its signal path nature EM features. We then chose the appropriate EM solver accordingly for the different sub-parts to do the modeling work to gain more speedup. The different parts' simulation can be done in parallel to further improve speed. Finally, we stitched them together through S-parameter modules. We went to great lengths to make all of these into an automatic flow named C&S to provide a single-button-click methodology. Numerical experiments show that this C&S flow is very efficient for the simulation of the structure with the long-transmission line channel included. For most of the cases, the speedup ratio is more than 10 times compared to traditional 3DEM solvers.

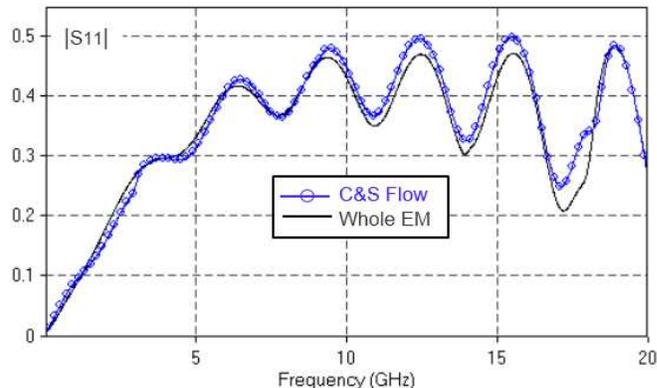


Fig.8 Comparison of the S-parameters between the two flows for the structure shown in figure 7.

#### ACKNOWLEDGMENT

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