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Fast and Simple Rigid-Flex PCB Bending EM Analysis Using Clarity 3D Solver

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Rigid-Flex PCBs have been used in many modern electronic devices (such as mobile phones, laptops, and wearables, among others), due to their form factor, light weight, and cost-effectiveness. Electromagnetic (EM) analysis of Rigid-Flex PCBs has always been a challenging task for many commercially available 3D numerical solver technologies (FEM and FDTD), due to the complexity in the 3D designs. Much of the complexity comes from bending of the board into small spaces and usage of hatched ground and power planes. In this paper, we first address the key challenges faced by the EM engineers and then propose a novel automated simulation workflow for a fast-to-market product development process. The proposed workflow, utilizing Cadence® Allegro® PCB Editor and Clarity™ 3D Solver, is the first of its kind in the PCB-EM community. Compared to alternative, highly manual processes, this flow is less error prone and very efficient in setting up the design for EM simulation. In addition, it runs faster than the other legacy 3DEM tools in the industry.

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Introduction

With the ever-growing demand for data speeds and small form factors in modern electronic devices, there is an increasing appetite for flexible circuits from the designers. Rigid-Flex PCBs (flexible PCBs), due to their flexibility in adjusting to the conformality and ability to fit into small spaces of the electronic devices, and low-cost manufacturing are preferred. There are many EDA tools in the market that allow PCB designers to create Rigid-Flex designs. Allegro PCB Editor is commonly utilized in the industry for designing Rigid-Flex PCBs, as it allows many designers to easily create and visualize the boards in real time. Some of its key features include [1-3]:

- **Rigid-Flex transformation (bending)**
- **Multiple flex laminates supporting flex circuit coverlays**
- **Zone management for rigid and flex**
- **Checking coverage and clearances—interlayer checks**

Figures 1(a) and 1(b) show a typical Rigid-Flex board, which usually consists of more than two different zones or areas, i.e., a rigid zone and a flex zone. A board might have multiple rigid and multiple flex zones (Figure 1(a)). The material stack-up of the two zones usually are different (Figure 1(c)). In addition, the mechanical engineer needs to provide the bend area, bend line, and bend radius to the PCB designer, who must create and adhere to various rules as described in [1].

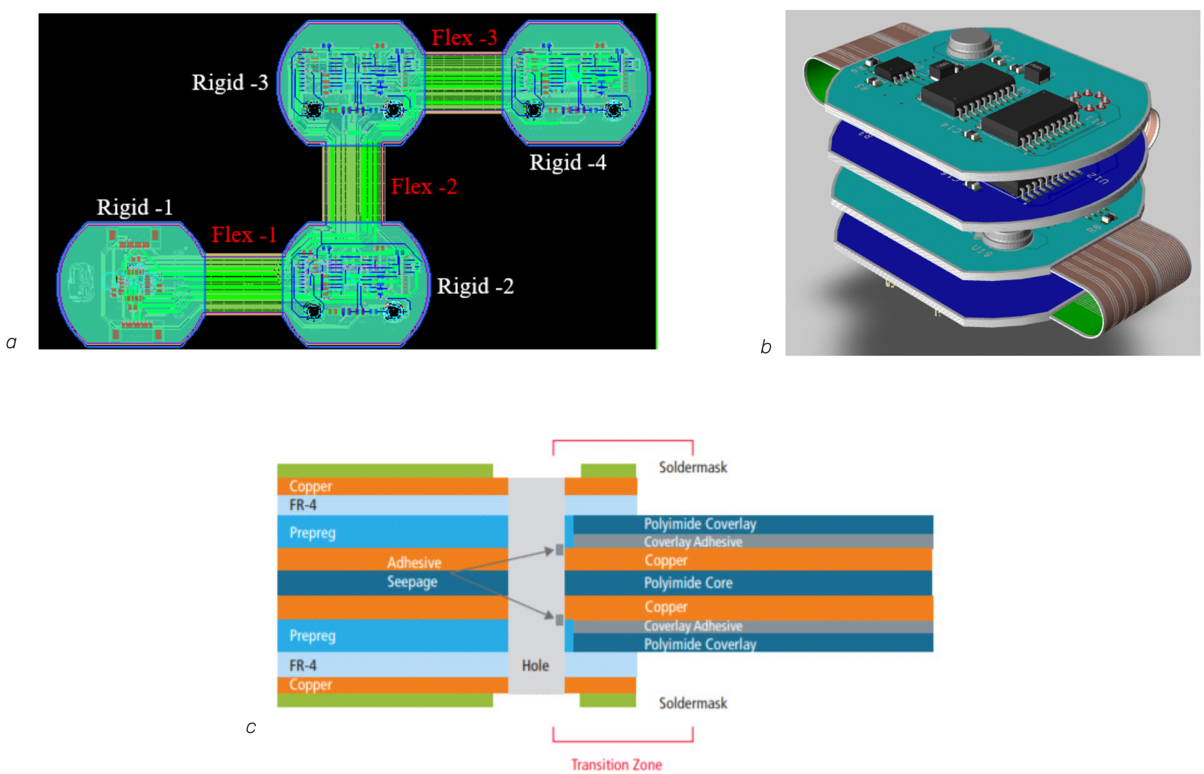


Figure 1: Typical Rigid-Flex PCB with (a) flat Rigid-Flex board with multiple rigid and flex zones, (b) 3D bended board, and (c) cross-section view of the layer stack-up

Once the PCB designer completes the board layout (ECAD) based on the mechanical engineer's guidelines (MCAD) to fit the various components in a given space, the board will then be handed to electrical engineers to study the complex high-frequency EM effects. To help understand these effects, usually a 3DEM full-wave solver is used—there are many 3DEM tools available in the market. However, these tools are time-consuming as the complexity of the boards increases and difficult to mesh (especially for Rigid-Flex boards).

To help address this issue, we use the Clarity 3D Solver [4] a 3DEM simulation software tool for designing critical interconnects for PCBs, IC packages, and system on IC (SoIC) designs. The Clarity 3D Solver lets you tackle the most complex EM challenges when designing systems for 5G, automotive, high-performance computing (HPC), and machine learning applications with gold-standard accuracy.

With a basic understanding of Rigid-Flex board design, this paper will concentrate on the EM simulation challenges faced by electrical engineers in analyzing the complex Rigid-Flex bended boards for EMI/EMC issues. We will then propose a novel workflow to help mitigate the bending analysis issues, and show some test cases of the complex Rigid-Flex bending EM analysis.

Challenges for Rigid-Flex Bending Analysis Using 3DEM Simulation

Once the layout is completed by the PCB designer, the ECAD data is imported into 3DEM full-wave tools for S-parameter extraction, EMI/EMC analysis, and other analyses. The main workflow followed by electrical designers for PCB analysis is the ECAD flow, wherein the PCB (e.g., .brd file) is imported in to 3DEM tools and the engineers focus on the regions of interest that are necessary for S-parameter extraction and cut the big board into smaller regions. Then they define the ports (excitations), including the solution frequency and frequency sweep, and run the simulation.

There exists a typical workflow for any PCB simulation where the flat PCB geometry is transferred into the 3DEM tool. This includes the layer stack-up information (material properties), component definitions for resistors, capacitors, inductors, and chip/packages. The advantage of this typical ECAD flow is the automatic creation of ports based on the component definitions imported from the layout tool.

This typical approach discussed is well established for flat PCBs. However, for the Rigid-Flex PCB, there are additional complexities, including the combined rigid board and an arbitrary 3D flex board that can be bent and twisted in any direction (Figure 1(b)). The traditional approach for a Rigid-Flex board is the MCAD flow, wherein the board is first imported into a 3D MCAD tool (e.g., Solidworks, Autocad) and then the 3D bending is performed. The bending is usually carried out by creating a bent structure and then the flat board is bent according to the bent structure (Figure 2). The bended board is then exported as a .step/.iges/.sat file and is then imported into 3DEM tools for S-parameter extraction.

The imported geometry is a group of dummy 3D objects without material property, component, and net definitions, as they are lost in the MCAD translation, as shown in Figure 3. The user then manually defines the material properties (for the dielectric and the metal objects) and manually creates the ports. This includes the solution frequency and frequency sweep, and runs the simulation. Many Rigid-Flex boards are complex in nature and the engineers must spend a significant amount of time in bending the board, defining material properties, and creating the ports.

In addition, due to the manual process involved in the MCAD flow, it is prone to human errors that can occur during the bending process (such as via, layer misalignments, and length mismatch), defining the material properties and creating the ports.

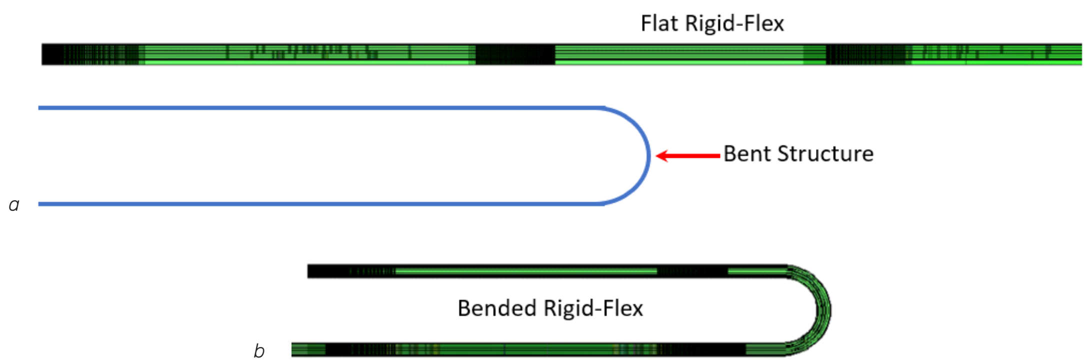


Figure 2: A typical bending process for Rigid-Flex boards is (a) bent structure to bend the flat Rigid-Flex and (b) bended Rigid-Flex after the bending process is carried out using the CAD tools

Even if the whole process is carefully carried out without any errors, the simulation may not run due to meshing issues caused by the dirty bended MCAD geometry (imported from the MCAD tool) and may take a long time for the simulation to complete because of the bad mesh quality. The user usually goes back to the MCAD tool to clean the geometry and repeats the process again in setting up the simulation. This whole process is a very time-consuming iterative effort (hours to several days, and in some cases weeks) and needs lot of user interaction.

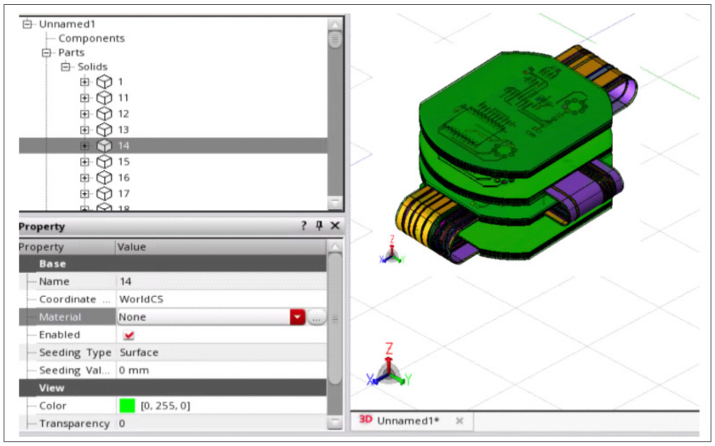


Figure 3: MCAD step file (.stp) imported into 3DEM tool

Cadence Rigid-Flex Solution

To alleviate this issue, we propose a new workflow for the Rigid-Flex bending analysis solution. The proposed workflow is easy to use, completely automated, requires minimum inputs from the designer, and setup takes only a few minutes.

Based on the guidelines provided by the mechanical engineer for the bends (bend radius and bend angles), the PCB designer sets these definitions in the ECAD layout and includes the zones. The ECAD layout will then be utilized by electrical engineers for EM analysis. Following are the steps for the Rigid-Flex bending analysis:

1. The PCB designer defines the bending parameters in Allegro PCB Editor. Figure 4(a) shows the layout of a Rigid-Flex PCB design in Allegro Release 17.4 with zones (defined for rigid board and flex board) and Figure 4(b) shows the bending regions and its corresponding bending parameters. The (.brd) file is then saved.

a

b

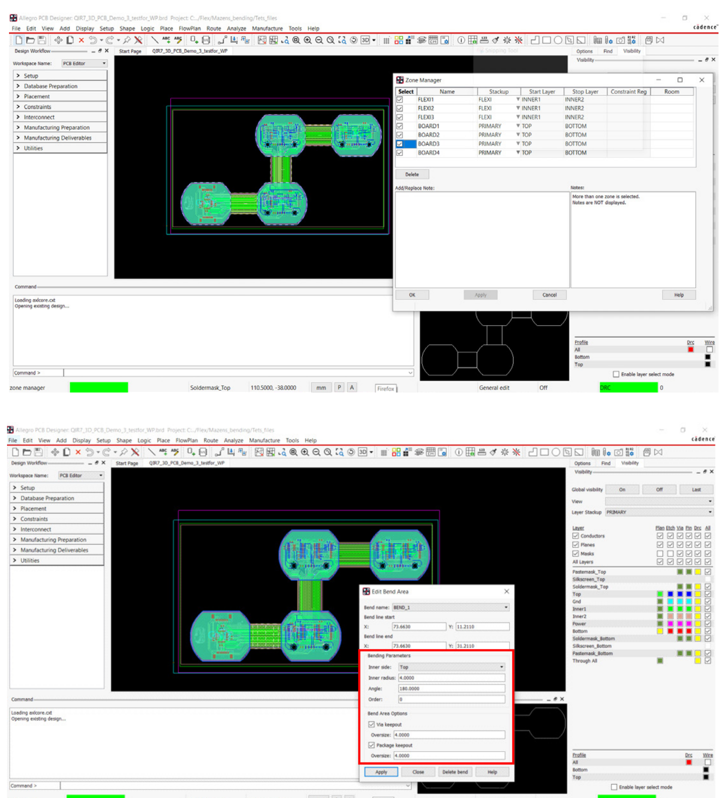


Figure 4: Rigid-Flex board layout in Allegro PCB Editor: (a) zone manager showing different defined zones (rigid and flex) and (b) bending parameters defined for the bend area.

2. The *.brd* (board file) is then imported into the Clarity 3D Solver layout environment as shown in Figure 5(a)—Open Clarity 3D Solver layout, *File open*. The user then verifies for the correctness of layer stack-up, nets, components, and different zones (with corresponding layer stack-ups) as shown in Figures 5(b) and 5(c).

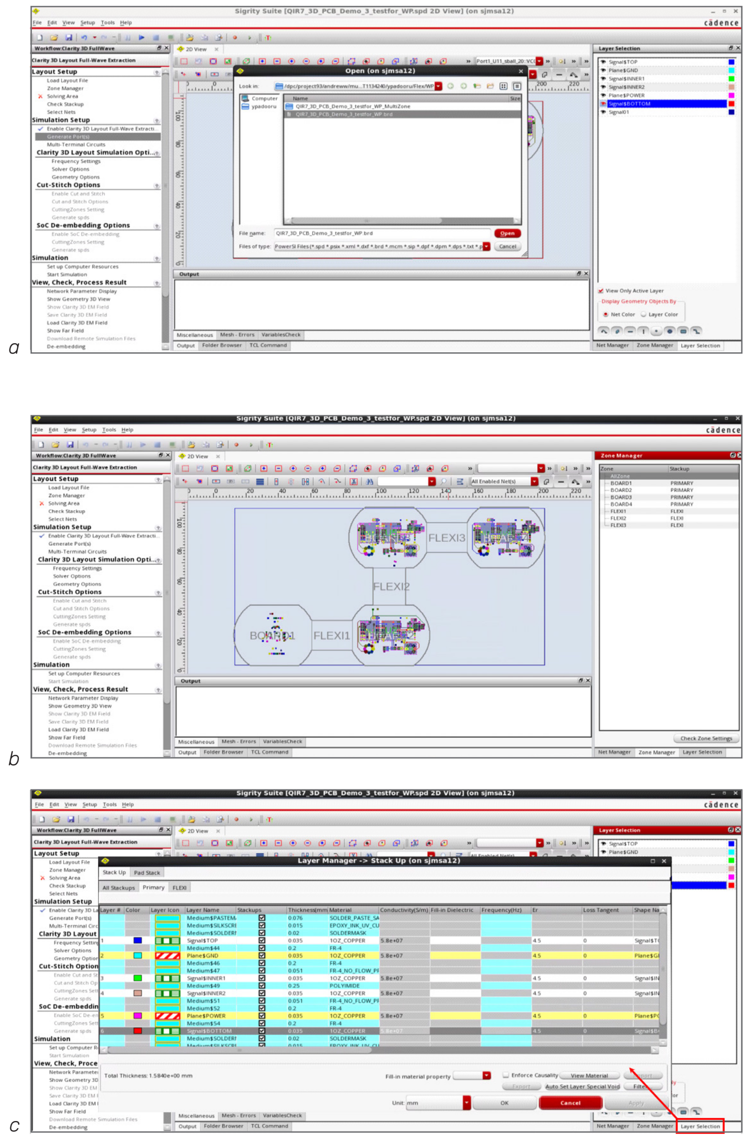


Figure 5: Setup in Clarity 3D Solver layout: (a) Importing .brd file, (b) verifying the zone manager for different zones, and (c) verifying the dielectric and metal stack-up definitions.

3. The user then defines the ports using the port wizard. The port wizard automatically identifies the different components (defined in Allegro PCB Editor) on the board and the user needs to select a particular set of components on which ports have to be created (as shown in Figure 6). Once the ports are created, save the design as .spd file.

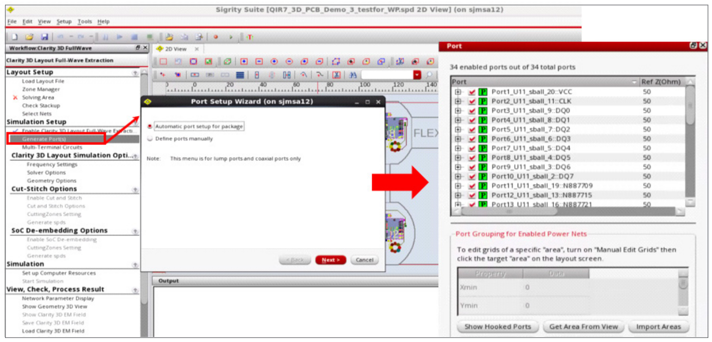


Figure 6: Automatic port set-up wizard in Clarity 3D Solver layout based on the component definitions.

4. Then import the .spd file (created in Step 3) in to Clarity 3D Solver 3D workbench environment. The Rigid-Flex board can now be viewed as a 3D bended geometry as shown in Figure 7. The board is bended automatically by the translation of the spd file, based on the bending parameters defined in Allegro PCB Editor (Step 1).

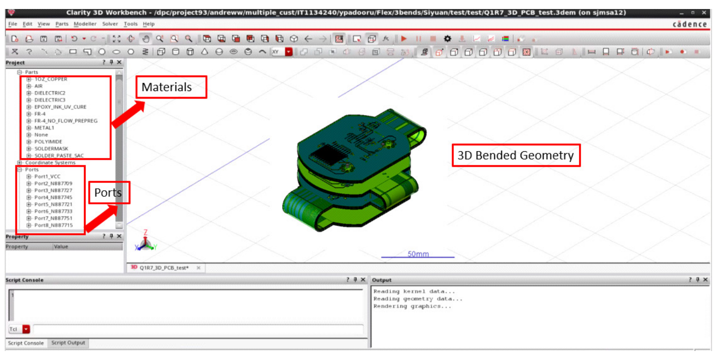


Figure 7: Clarity 3D Solver workbench showing the bended geometry with the material properties and ports being automatically translated through the .spd import (generated from Clarity 3D Solver layout).

5. Input the solution frequency and frequency sweeps and run the simulation.

Figure 8 compares the proposed workflow with a typical workflow. The proposed workflow is fully automated (it needs minimum inputs from the user to set up the simulation), is very efficient, and provides 100% simulation success.

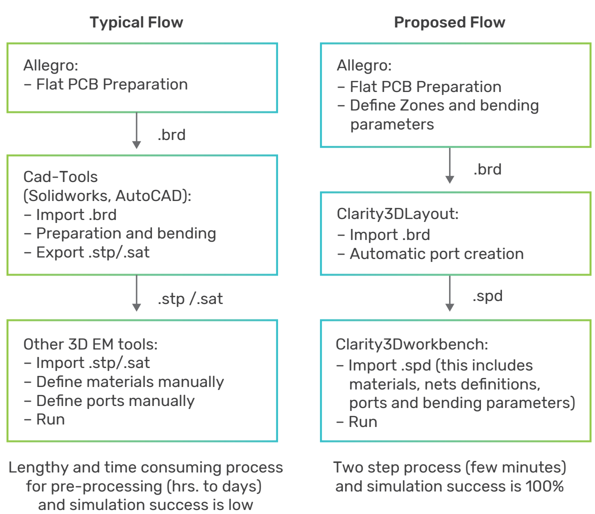


Figure 8: Comparison of the existing workflow in the industry and the proposed workflow

Examples of Rigid-Flex EM Analysis

To demonstrate the effectiveness of the new workflow proposed in the previous section, here, we consider two test cases (as shown in Figures 9 and 13). Even though many Rigid-Flex PCBs were analyzed, for the sake of brevity we will concentrate on two cases. In the test cases considered in this section, the Rigid-Flex PCBs have been designed by the PCB engineers (with zones and bending parameters pre-defined) and we will focus only on the EM simulation runs carried out by the Clarity 3D Solver. We will follow Steps 2 to 5 discussed in the previous section.

Case 1

In Case 1, we will first consider a Rigid-Flex board with three flex (bend) regions and four rigid regions as shown in Figures 9(a) and 9(b) along with the signal and ground layers. The layer stack-up definitions for the rigid and flex regions are different, which can be seen from the cross-section view shown in Figure 9(c). This clearly shows the effectiveness of the proposed workflow as discussed in the previous section, i.e., the translation of *.brd* defined with different zones into the Clarity 3D Solver without much user intervention. The bending parameters are given in Table 1. The transmission/signal lines start at rigid board-1, go through flex-1-rigid-2-flex-2-rigid-3-flex-3 and end on rigid-4. The ports are defined at rigid-1 and rigid-4, respectively (as discussed in Step 3 of the guidelines). After bending, the ports end on the top and bottom of the board as shown in Figure 9(c). The simulation is then carried out by the Clarity 3D Solver (full-wave FEM solver) at 10GHz solution frequency with frequency sweep range from 10MHz-10GHz. The Clarity 3D Solver's automatic adaptive finite element mesh refinement technology provides consistent accuracy for the Rigid-Flex PCB. It uses the industry-leading parallelization technology to ensure that both meshing and frequency sweeping can be partitioned and parallelized across as multiple computers with varying computer configurations, thereby considerably reducing the time to solve the entire complex Rigid-Flex structure. The insertion and return loss for some of the nets are shown in Figure 10. The mesh plots shown in Figure 11 indicate how well the bending nature of the flex PCB is considered and modeled in the Clarity 3D Solver. Figure 12 shows the surface current density on the metal layers.

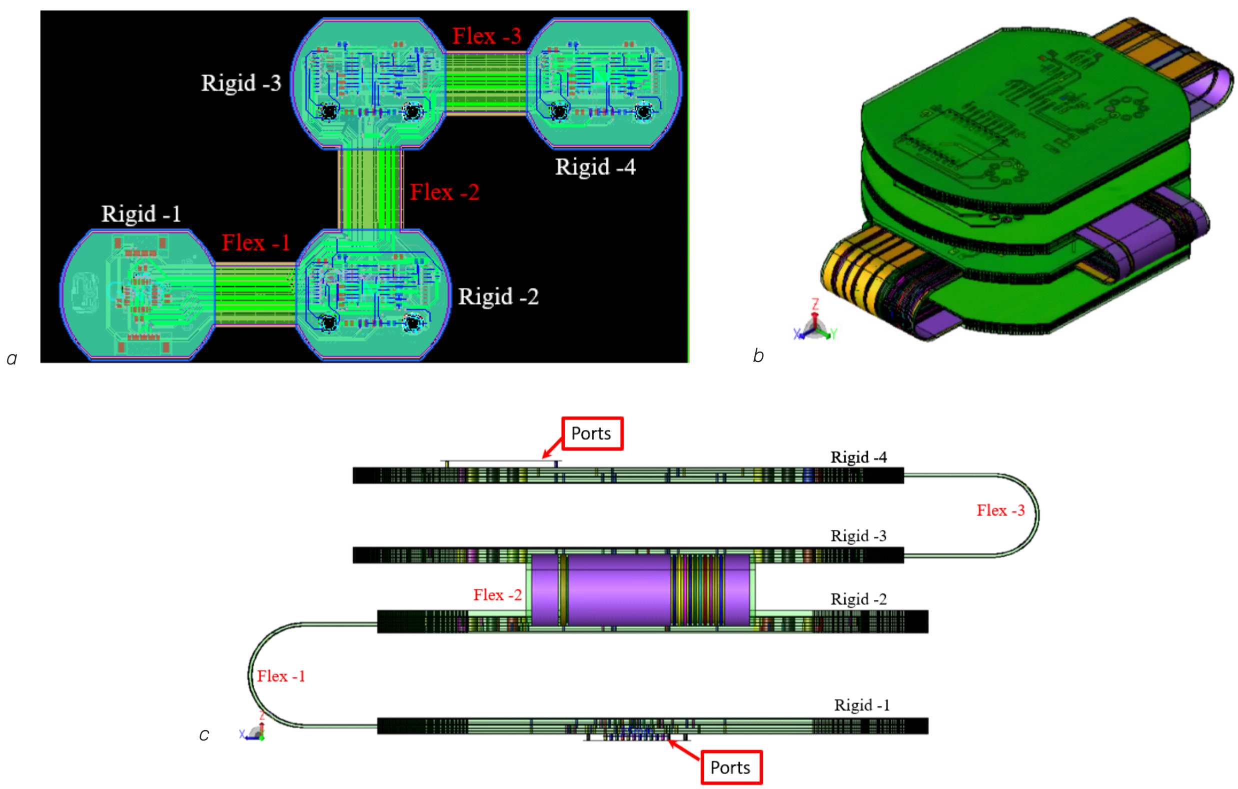


Figure 9: Three-bend Rigid-Flex board with (a) layout in Allegro PCB Editor showing four rigid zones and three flex zones, (b) 3D-, and (c) cross-section views in the Clarity 3D Solver workbench

	Bending Radius	Bending Angle
Bend-1	4 mm	180 deg
Bend-2	4 mm	180 deg
Bend-3	4 mm	180 deg

Table 1: Bending parameters for the three-bend case shown in Figure 9

The bend radius and angle given in Table 1 are associated with the respective flex regions shown in Figure 9.

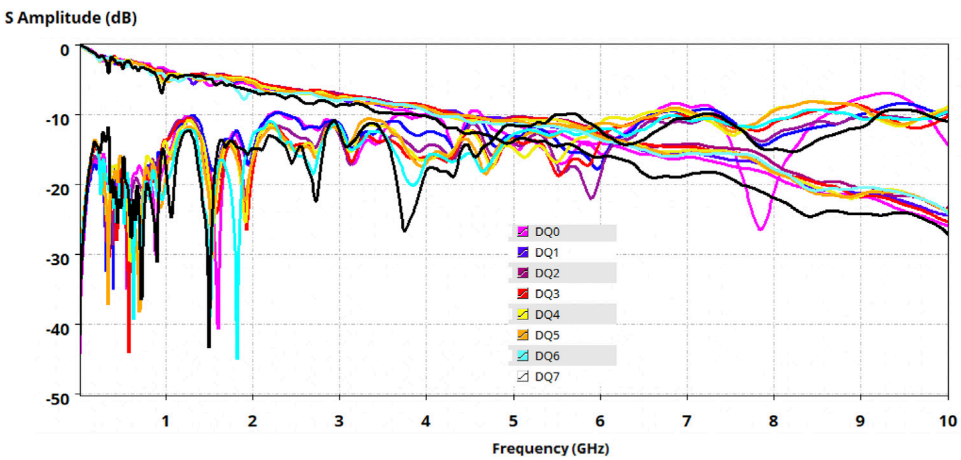


Figure 10: S-parameters showing insertion and return loss for some of the selected nets

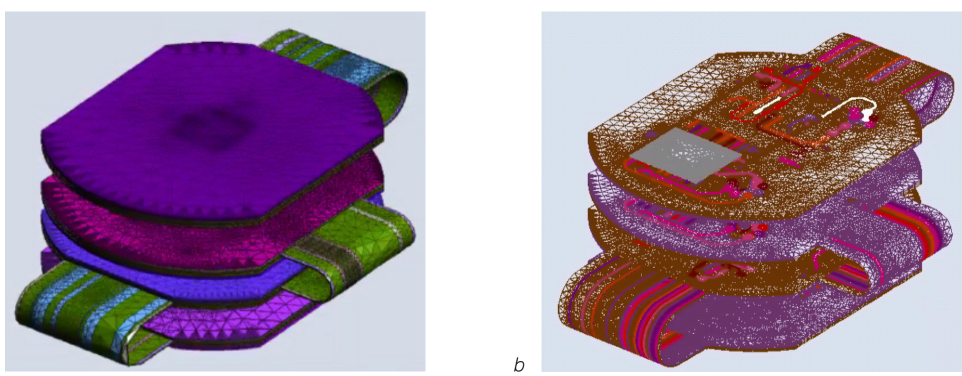
a  b

Figure 11: Mesh plots for the three-bend board: (a) on the dielectric layers and (b) on the metal layers

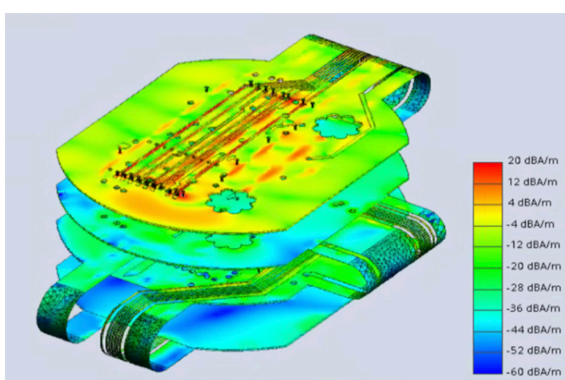


Figure 12: Surface current density on the metal layers when all the ports are excited

Case 2

In Case 2, we consider a different type of three-bend Rigid-Flex case, which has three flex zones and two rigid zones as shown in Figure 13(a). The bending parameters defined in the Allegro layout are given in Table 2. We again follow the steps given in the guidelines, and the corresponding structure after translation into the Clarity 3D Solver is shown in Figures 13(b) and 13(c). The signal lines start at rigid-1, run through flex-1-flex-2-flex-3, and end on rigid-2, as shown in Figure 13(a). The ground plane consists of a diagonal-both cross-hatch (Xhatch) plane with line width 0.3mm and spacing 0.3mm. The ports are defined on the two rigid sections as shown in Figure 13(c). Solution frequency of 10GHz with frequency sweep ranging from 10MHz – 10GHz is used for the simulation.

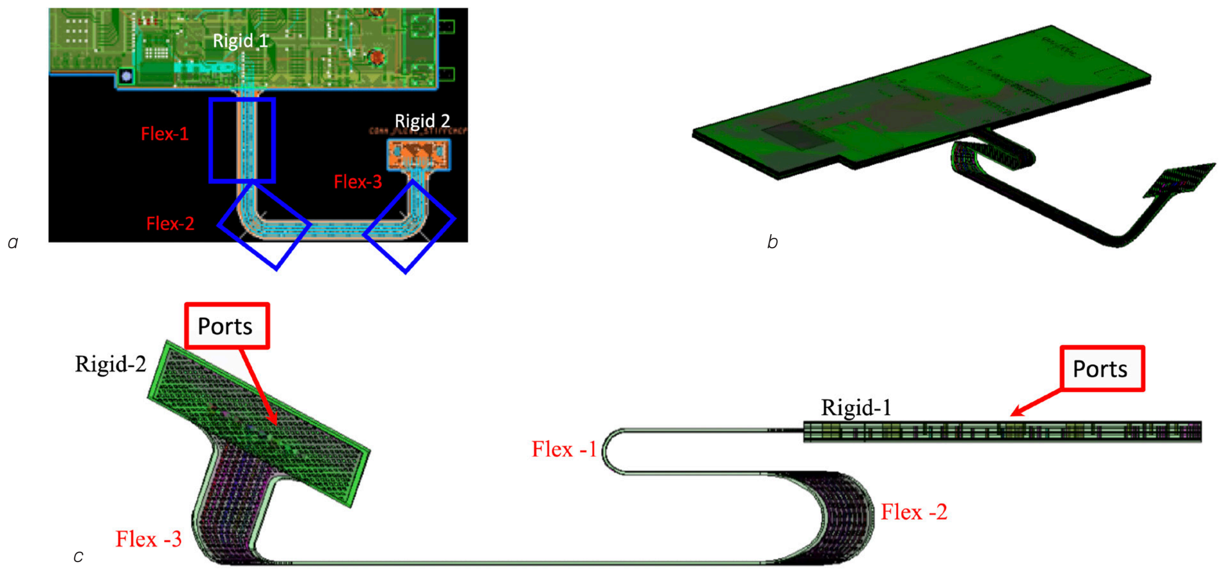


Figure 13: Three-bend Rigid-Flex board with (a) layout in Allegro PCB Editor showing two rigid zones and three flex zones, (b) 3D-, and (c) cross-section views in the Clarity 3D Solver workbench

	Bending Radius	Bending Angle
Bend-1	6 mm	180 deg
Bend-2	5 mm	200 deg
Bend-3	20 mm	45 deg

Table 2: Bending parameters for the three-bend case shown in Figure 13

The S-parameter plots for the insertion and return loss are shown in Figure 14. The mesh and current density plots shown in Figures 15 and 16 indicates how detailed the whole complex Rigid-Flex PCB is modeled and analyzed (including the Xhatch ground planes, bending regions, and signal nets) using the Clarity 3D solver.

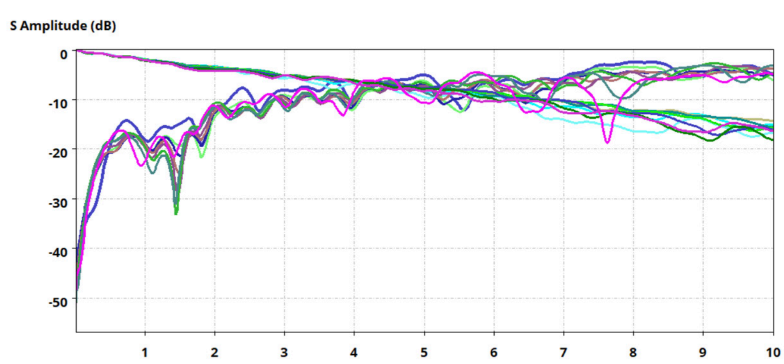


Figure 14: Insertion and return loss S-parameters for the three-bend case shown in Figure 13 for some of the selected nets

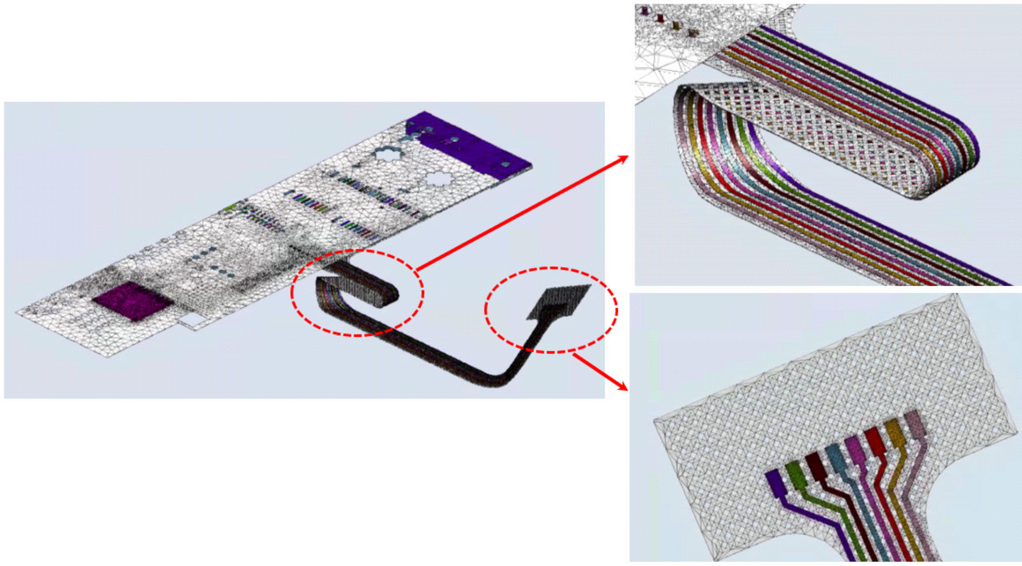


Figure 15: Mesh plot on the metal layers—insets show the zoomed regions of the flex and rigid regions

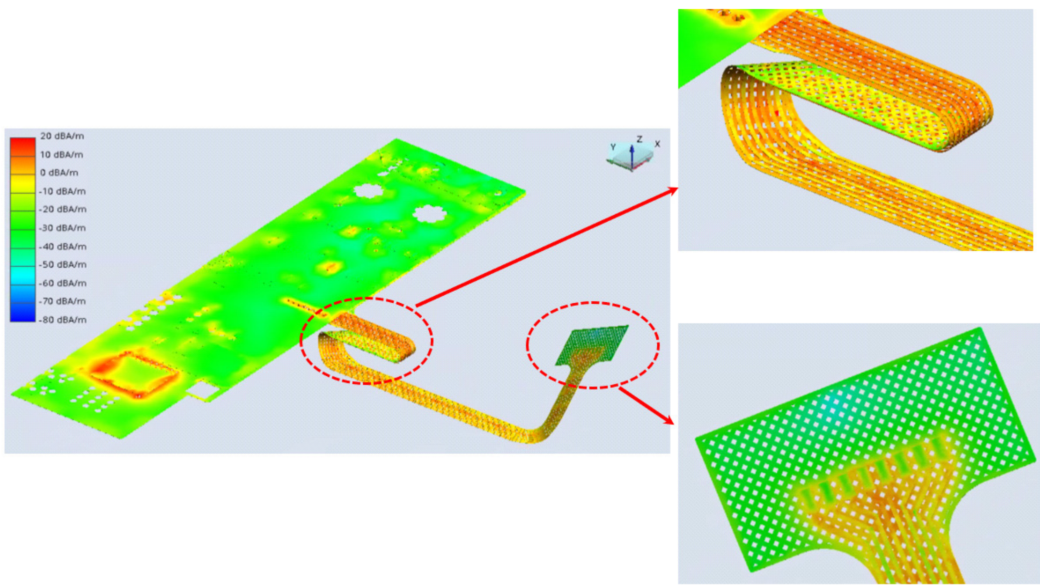


Figure 16: Current density plots on the metal layers—insets show the zoomed regions of the flex and rigid regions

Conclusions

In this paper, we presented a simple and efficient workflow for the EM analysis of Rigid-Flex bending using the Clarity 3D Solver, which saves both PCB and EM designers a considerable amount of time in setting up and analyzing the design. The proposed workflow is the first of its kind in the PCB-EM community (among the available 3D numerical FEM solvers in the industry). The proposed workflow is verified using two different test cases and can be used by various EM engineers for mitigating the complex EMI issues that exist in present day electronic devices for a quick-to-market product development process.

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