A Guide to Accelerating Your Design Timeline With Electromagnetic Analysis

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Content

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Introduction

An engineer's toolkit contains various solvers, each offering different trade-offs between accuracy and simulation time. It's up to you to decide which resources are necessary at each stage of the design process. 3D planar, or hybrid, solvers may be a sufficient choice when needing to make a quick decision, such as choosing a layer to route on. These solvers allow you to understand the fundamentals of circuit behavior through their rapid assessment and fast handling of a design section. However, modern, full-wave 3D extraction is a key step in identifying SI and PI issues and serves as a critical tool for signoff before sending a design to fabrication

Three-dimensional finite element method (3D FEM) solvers are notorious for being computationally cumbersome and time-consuming. These challenges force many engineers to segment their design using the cut-and-stitch approach to distribute the modeling task across cores. This approach can be error-prone for those inexperienced with computer-aided design (CAD), as designers may remove too much from the model and miss out on crucial electromagnetic (EM) behaviors, causing it to fail performance requirements. The Clarity 3D solver eliminates the typical time constraints with a parallelized matrix solver, an elastic compute architecture, and cloud-optimized distribution.

This ebook discusses various simulation approaches aimed at accelerating design timelines without compromising result accuracy and details how the Clarity 3D FEM solver shortens the time needed to generate precise models of your entire structure.

The Need for EM Analysis

The complexity of high-speed PCB designs has created the need for specialized electromagnetic analysis tools, which convert the physical description of the conductors in a circuit board into a form that allows for analysis. Such analyses could include a planar analysis, focusing on flat 2D structures or the "meshing" of 3D conductors. 3D meshing enables the use of numerical methods such as the finite element method (FEM) or method of moments (MoM) techniques (**Figure 1**). After the simulation area has been discretized into smaller elements, you can solve it using Maxwell's equations. Ultimately, the analysis yields a model, typically S-parameters, which can be used to verify performance.

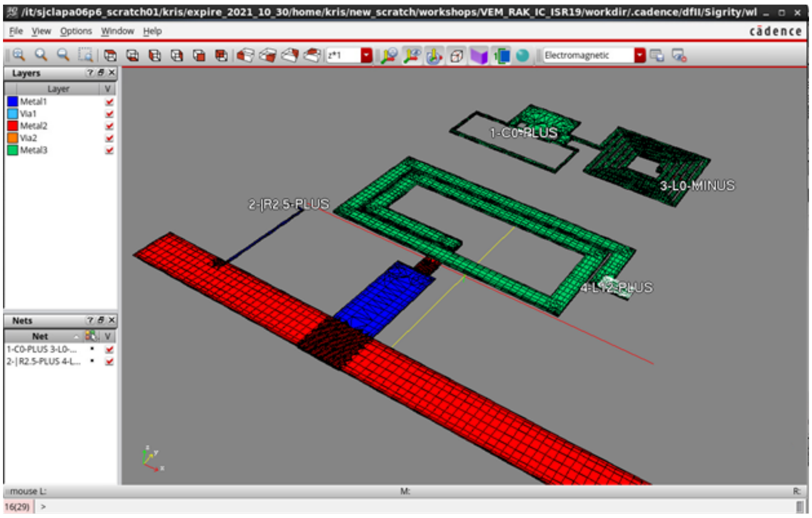

Figure 1: *Meshing can accurately represent and analyze the complex 3D geometries from which SI problems often stem. Source: Cadence*

3D Full-Wave/Arbitrary vs 2D/Hybrid Field Solvers

Figure 2 shows the numerous solvers offered by Cadence to assist with simulation. This section briefly describes the basic 2D cross-section, 3D planar (hybrid), and full-wave 3D FEM solvers.

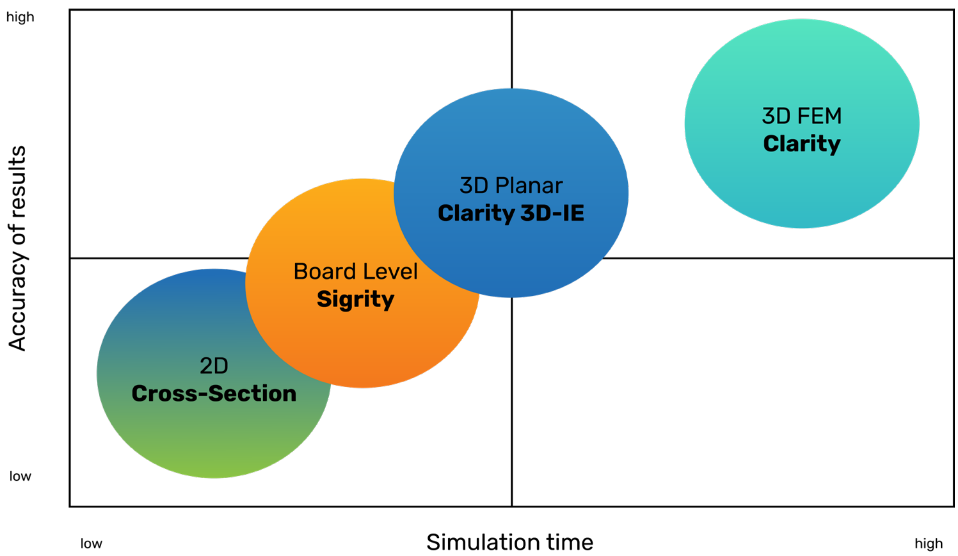

Figure 2: *Result accuracy versus simulation time.*

2D Cross-Section

2D cross-section solvers focus on flat structures, such as the cross sections of longitudinally uniform waveguides, strips, or slots. This enables a small, bounded 2D region where current or voltage calculations can be performed quickly using numerical methods such as FEM, MoM, and the finite-difference method (FDM). However, this approach might be too constrained even for basic PCBs.

3D Planar or Hybrid

Sigrity employs a 3D planar (hybrid) solver, primarily using a 2D algorithm focused on flat structures. It also incorporates heuristics that enable users to quickly achieve results closely matching those of a full 3D solver. Generally, these solvers make assumptions in the third dimension, such as a constant current in the horizontal or vertical direction, and have predefined EM models for 3D geometries. These assumptions can reduce the accuracy of the results.

You can leverage a 3D planar solver to gain rapid insight into circuit performance and make efficient design decisions. This is more rudimentary than 3D FEM analysis but may be suitable for quickly understanding the performance of relatively planar geometries. For example, it can help assess where reflections occur across the package's entire bandwidth to identify and fine-tune potential design issues.

3D Full-Wave or 3D Arbitrary

A 3D arbitrary solver is essential for multi-layer PCBs and large structures that extend beyond the PCB plane, as well as IC packages and system-in-package designs. This solver provides a more comprehensive view of signal dynamics as it travels through the channel. However, this requires additional solution time because the program must solve for fields in the entire 3D volume.

In **Figure 3**, you can see the 3-step approach taken by any 3D FEM solver. First, the geometry is imported via a mechanical computer-aided design (MCAD), electronic computer-aided design (ECAD), or database to create the initial mesh. This mesh discretizes the geometry, transforming Maxwell's equations into a linear matrix system that can be solved using FEM. However, this discretization is not always ideal; the first established meshing can introduce inaccuracies in more complex 3D structures. Such errors can yield results that do not account for the complexities in EM behavior.

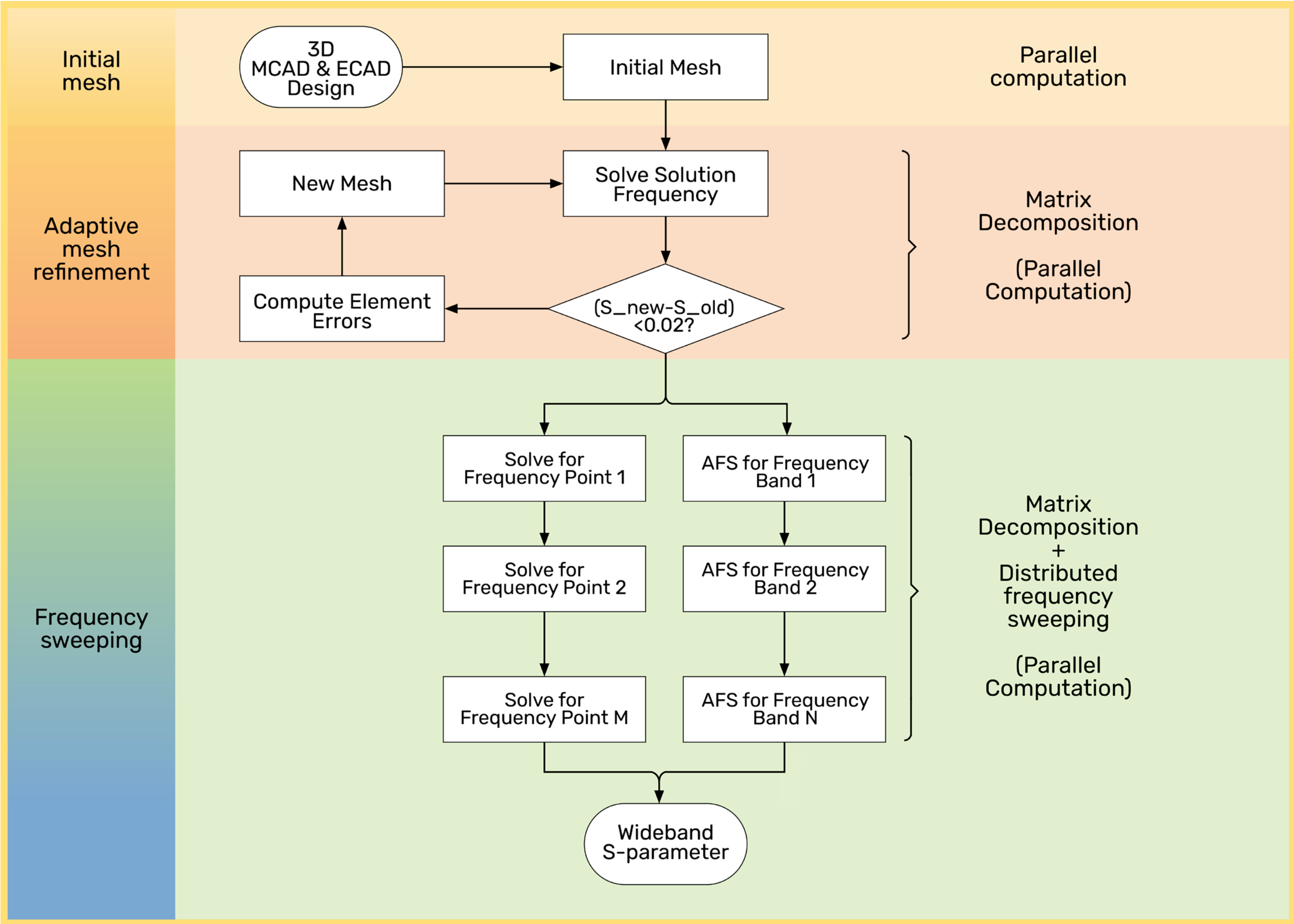

Figure 3: *The typical approach of 3D FEM solvers.*

Increasing mesh density can help you achieve better accuracy. If the mesh were infinitely dense, the numerical solution from the simulation would converge to the exact solution of Maxwell's equations. However, this requires balancing practical constraints, such as computational time and memory resources.

This is where adaptive mesh refinement (AMR) comes into play. The mesh is adapted to resolve areas of EM importance for the structures. In other words, the mesh density increases in areas where field behavior is more nuanced, e.g., 3D structures. This must be done while keeping computational costs low. Mesh adaptation stops after a maximum number of passes, limiting the calculation time to achieve results. Typically, s-parameters between consecutive iterations are compared and the change between the s-parameters (ΔS) must be below a set threshold for the stop criterion, or convergence criterion, to be met.

After this, frequency sweeping is performed to solve for the linear matrices at each frequency point (**Figure 4**). Note, AMR is typically performed on a single master, which is why the task of 3D FEM simulation on a complex structure can require a multi-terabyte machine and can take days to converge.

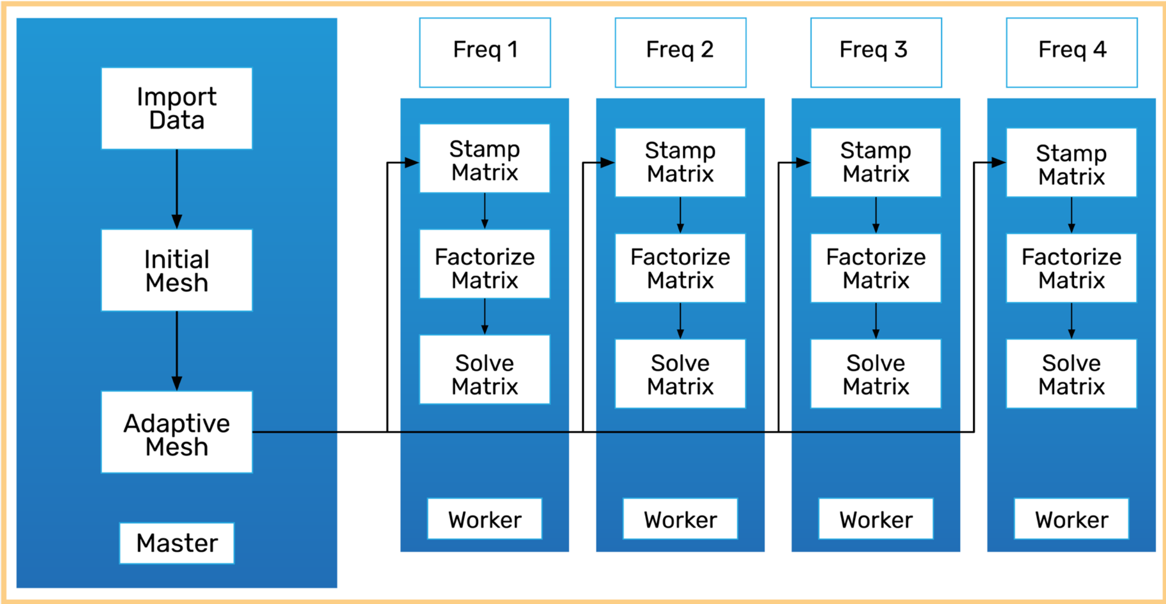

Figure 4: *Standard 3D FEM process with AMR performed on a single platform, creating a computational bottleneck.*

Clarity 3D FEM Solver

As illustrated in Figure 5, the Clarity 3D FEM solver enables both meshing and frequency sweeping to be partitioned and parallelized across multiple computers, computer configurations, and cores. So, instead of solving for one full frequency on one machine and another on a different machine, the process utilizes automatic, fine-grained parallelization. This parallelization is based on the computational workload that can be handled within the memory limitations of each machine.

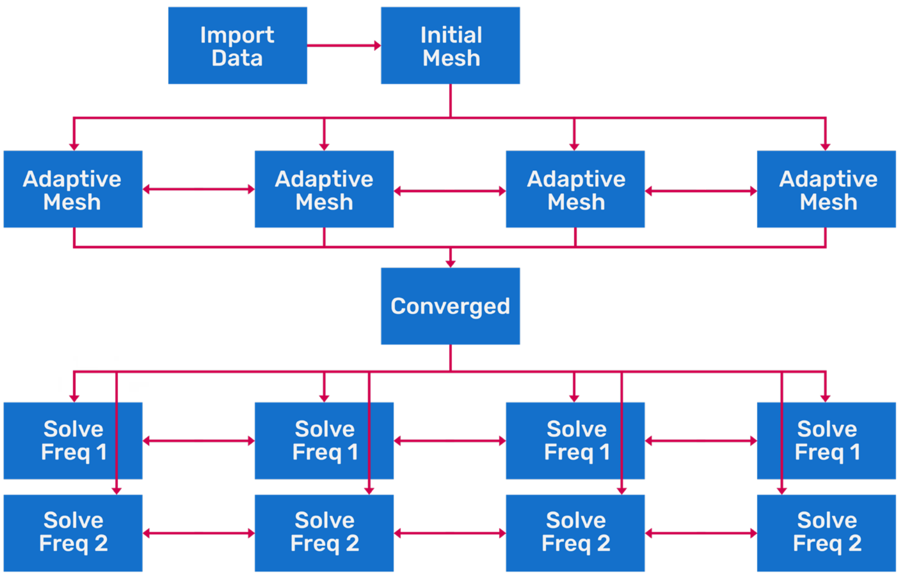

Figure 5: *Clarity uses a parallelized matrix solver to distribute the large matrices typically built by FEM solvers across multiple machines.*

This method results in the entire AMR process (and frequency sweep) not having to fit within the memory of one machine, and performance can scale with core count instead of manually cutting large structures into smaller pieces. These characteristics enable the use of different compute architecture sizes to distribute the simulation and increase the 3D full-wave simulation time 10-20x.

The increasing number of compute nodes needed to solve the EM problem brings into question the robustness of the model. It is not uncommon for jobs to fail for any number of reasons, or get killed and migrated to another machine by the farm management system. For example, if this happens to 1/100 jobs, you would not want the entire simulation to fail. Clarity matrix solver is fault-tolerant, so if any computation node goes offline, it can quickly recover, minimizing the cost of using cloud resources.

The Segmented Approach

Cut-and-Stitch Design Flow

Some engineers still take the cut-and-stitch approach and segment the aggregate model to reduce the memory requirements of the simulation. The 3D cut-and-stitch simulation flow is as follows:

1. A boundary is defined to cut the design for 3D EM simulation.
2. The region is partitioned into multiple zones by drawing cut lines.
3. The zones are simulated individually.
4. AC circuit analysis is automatically applied to merge the individual results.

Figure 6 uses the cut-and-stitch feature in Sigrity, where nets of interest are extracted from the PCB, and the entire channel performance is obtained by stitching together the results to form an overall outcome.

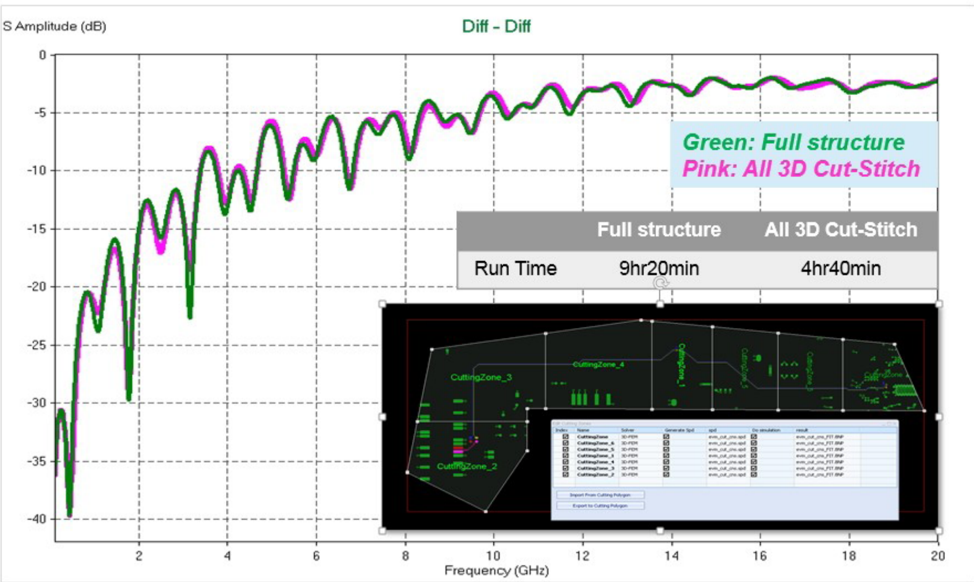

Figure 6: *Simulation run time on a full structure vs. the Sigrity EM cut-and-stitch design flow. Source: Cadence*

The benefit of this method is the enablement of high-resolution meshing to produce more accurate results in a single server setup. However, the iterative optimizations required for each segment are time-consuming, and the artificial segmentation may hide global resonance conditions. While the parallelized Clarity 3D FEM solver approach provides easy access to full-structure simulation results, cut-and-stitch may be more suitable for designers with limited computing resources. It also works well for those who want an idea of full-structure performance but are not yet at the sign-off stage.

Cut-and-Stitch With Mixed Solver Design Flow

You can take the cut-and-switch process further by using the sub-designs already established after segmentation and simulating them through a combination of full-wave 3D and hybrid (3D planar) solvers. This speeds up simulation time and, if carefully done, will not massively impact result accuracy. The steps for the mixed solver approach are as follows:

1. Start with the full design layout and disable most signal nets.
2. Perform a hybrid analysis of the full structure.
3. Partition the complete structure into multiple zones by drawing cut lines. Perform a hybrid analysis of the segmented design and compare it with the hybrid analysis of the full structure.
4. Set up the cut-and-stitch workflow with mixed solvers by selecting the solver required for each zone.
5. Optional: Choose more zones to be simulated by the 3D solver. In the extreme, all zones can be simulated by the 3D solver. Then, compare these results with those of the mixed solver analysis.
6. Optional: Perform a 3D full-wave analysis on the entire structure and compare it with the results of the mixed solver analysis.

These steps are demonstrated in **Figure 7** for the IC package of a SERDES channel, which contains two differential pair interconnects and transitions to both the chip and the board. It also lists the simulation time and memory consumption for each demo step.

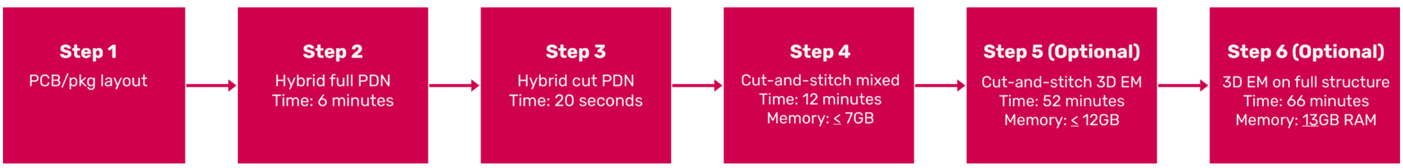

Figure 7: *Mixed solver cut-and-stitch simulation flow for IC package SERDES channel.*
Source: Cadence

In step 1, the full power delivery network (PDN) structure of the SERDES channel is maintained, and all but a few of the signal nets of interest are disabled. You can explore stages two through six of the demo in greater detail in **Figure 8.**

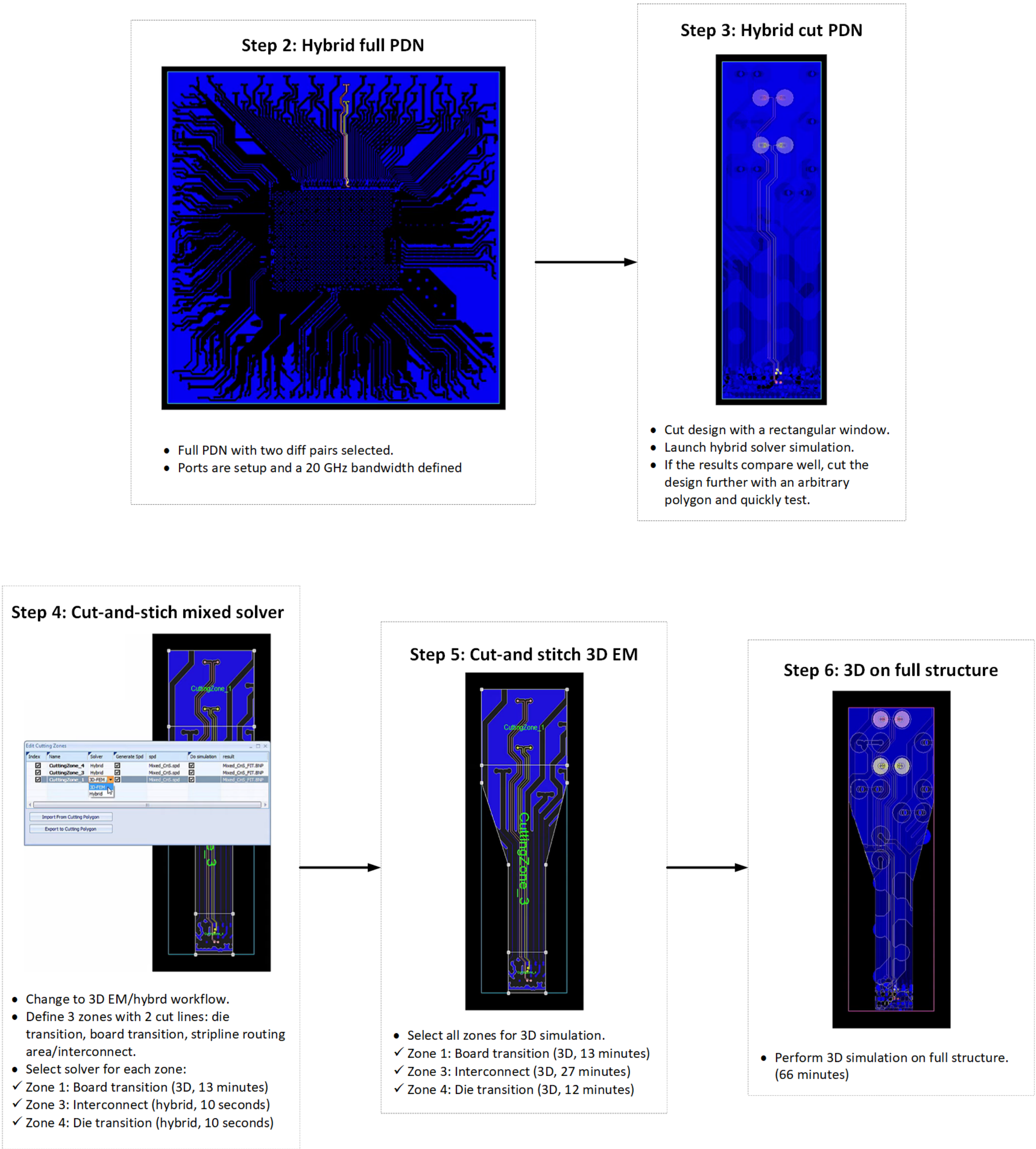

Figure 8: *A breakdown of the mixed solver workflow with a SERDES channel demo in Sigrity. Source: Cadence*

Step two establishes the baseline for comparison in step three, which is the hybrid solver cut-and-stitch phase. Comparable results mean you have not excluded PDN effects, such as resonance, and the design hasn't been excessively cut, preventing proper local simulation results.

Finally, in step four, you perform the mixed solver simulation approach by choosing the appropriate solver for each zone and launching the simulation. In Figure 8's demo, the hybrid solver extraction on the full PDN revealed that the board-side transition dominated performance, prompting the use of a 3D solver solely for this area. (Zone 1).

Steps five and six are optional to ensure all EM effects are considered. You can view these steps as a validation measure.

The hybrid/3D simulation process may empower engineers to perform iterative optimizations for tight collaboration across engineering specialties throughout the design process. Once again, it is important to note that the accuracy of the results relies on the level of engineering expertise required to cut and stitch complex designs.

Choosing the Ideal Extraction Technology

Ultimately, there are various extraction technologies that you can use:

- 3D planar (hybrid)
- 3D FEM cut-and-stitch
- Mixed solver (3D FEM + hybrid) cut-and-stitch
- 3D FEM on the full structure

However, deciding which technology is best for you depends on multiple factors, such as the complexity of the design, required accuracy, and project resources.

Hybrid

The 3D planar (hybrid) solver can be used for a first-pass look at the amplitude and phase characteristics of the differential-mode s-parameters. Initial layout insights can be gained by monitoring insertion and return loss behavior, as well as by adjusting the layout to observe "macro-level" changes. Early application of the hybrid simulation to the full structure allows the designer to understand the channel's fundamental performance, ensuring local 3D simulation success in the cut-and-stitch simulation design flow.

Cut-and-Stitch

To make more fine-tuned adjustments or observations, the 3D FEM solver will likely need to be implemented. The cut-and-stitch methodology can reduce simulation time, regardless of design complexity, by utilizing either a hybrid or 3D FEM solver in each zone. Regions with complex 3D structures that may contribute to SI/PI issues, such as vias, via stubs, non-uniform return paths, bumps, and bond wires, can be assigned to the 3D FEM solver. This allows well-behaved planar geometries, like uniform return paths or areas with long transmission lines, to be delegated to the hybrid solver. This segmented model methodology lets designers have a somewhat accurate, local design assessment within minutes.

3D FEM

Finally, the Clarity 3D FEM solver is a powerful tool for sign-off, accelerating the full-wave 3D analysis of the structure. Parallelizing AMR and the frequency sweep across multiple cores eliminates the convergence issues caused by the memory limitations of a single compute node/master. Furthermore, the matrix solver is parallelized across both compute and memory, using less RAM per parallel job. The robust algorithms handle the unpredictable job terminations that can crop up with these larger-scale computing operations.

Resolving Your Problem With the Right Solver

Cadence offers a wide range of EM analysis tools that can be used during and after the circuit and layout design process. These tools include EMX and AXIEM, which leverage hybrid solvers; Sigrity, which allows for the cut-and-stitch design flow; and Clarity, which enables highly parallelized full-wave analysis. Depending on the type of design (e.g., high-speed serial link, millimeter-wave transmission lines, RF passive components, RF modules, antennas), each tool can be used at specific points in the design process to improve performance iteratively. The Clarity 3D solver is optimized for complex structures and is ideal for signoff with any design, regardless of its end application.

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