

The Next-Generation of Circuit Simulation in RF EDA

Programmatic Control, AI Integration, and Automated Workflows for High-Frequency Design

Introduction

Radio-Frequency (RF) Electronic Design Automation (EDA) is at a turning point. Historically, engineers adapted their workflows to rigid software tools, often sacrificing flexibility and efficiency. With the rise of increasingly complex, multi-domain hardware systems, these constraints are no longer sustainable.

Keysight is reimagining RF simulation as a **programmatically controlled, extensible platform** — an approach that integrates tightly with measurement science, leverages automation, and opens the door to Artificial Intelligence (AI).

This whitepaper explores:

- The **limitations of traditional RF simulators** and why a new architecture is needed.
- **Key design motives** for developing a next-generation RF simulation engine.
- **Immediate productivity benefits** from Python integration, troubleshooting aids, and parallel optimization.
- **Future possibilities** for automated workflows, no-code design sequencing, and AI-driven exploration.

The result is an RF simulator that behaves more like an instrument: portable, automatable, and seamlessly pluggable into diverse workflows — unlocking higher productivity, faster innovation, and better first-pass design success.

The Limits of Traditional RF Simulation

Electronic Design Automation (EDA) tools have traditionally been vendor-defined ecosystems, with workflows shaped by software capabilities rather than engineering intent. When engineers adopt a new tool, they must often conform their design process to the tool's structure — its interface, data formats, and execution model. This dynamic worked when designs were simpler, workflows were linear, and tool interoperability was less critical. But RF systems have changed dramatically.

As hardware complexity has grown, so too has the need for multi-domain workflows that span Electromagnetic (EM), circuit, thermal, and system-level analyses. No single tool can cover the entire design spectrum effectively. To keep pace, design teams have adopted combinations of commercial EDA software, open-source utilities, and homegrown tools tailored to specific tasks.

While effective in isolation, these patchwork workflows introduce integration friction — every tool switch comes with additional steps, file translations, and synchronization overhead.

Industry efforts like Si2's OpenAccess ¹ were developed to address this by standardizing APIs and data repositories, and they have indeed improved interoperability across some EDA domains.

However, RF simulators are often deeply tied to proprietary engines and closed user interfaces, making them harder to integrate into modern, modular workflows that demand agility and automation.

Today, RF engineers encounter persistent bottlenecks that slow innovation and limit flexibility, including:

- Rigid user interfaces that constrain how workflows can be structured or automated.
- Closed “black-box” simulator architectures that trap valuable intermediate data behind fixed GUIs.
- Limited interoperability across heterogeneous design environments, preventing seamless data flow.
- Slow or fragmented optimization processes struggle to scale with the growing complexity of multi-band, multi-technology designs.

These limitations have a cascading impact on design cycles. When workflows are inflexible, switching tools or adding new capabilities is risky and costly. Optimization processes take longer, debugging becomes more difficult, and opportunities for automation and AI integration remain untapped.

Addressing these challenges requires more than incremental feature updates. It calls for a fundamental rethinking of what an RF simulator should be — moving from a closed, static tool toward an open, extensible platform that enables collaboration, automation, and continuous innovation.

¹ Si2 OpenAccess industry interoperability initiatives.

Motives for Re-Architecting RF Simulation

Delivering the vision of a simulator-as-instrument requires more than layering features onto an existing engine. Over time, legacy simulators accumulate complexity that makes adding new capabilities costly, risky, or impractical. At a certain point, starting fresh with a re-architected platform becomes the most effective way to meet evolving design needs.

Keysight's research ¹ identified several core motives for this re-architecture — ranging from usability improvements to breakthrough performance gains and future-proofing for AI. Each motive reflects practical challenges faced by engineers today and opportunities to dramatically enhance productivity tomorrow.

Modernizing the user interface

Current simulators often clutter schematics with probes and controllers that disrupt Layout-Versus-Schematic (LVS) verification (see figure 1). A streamlined UI would let simulations run directly from schematics — reducing errors and improving workflow clarity.

Programmatic execution control

Python scripting has already proven useful for customizing workflows. A programmatically controlled simulator expands this further with:

- Headless simulation (API-only invocation).
- Customizable UIs and data pipelines.
- Seamless integration of Python analysis functions.

Pre-processing for smarter workflows

Instead of running simulations across entire data sets, pre-processing allows selective computation and direct filtering during execution — saving time and improving data visualization.

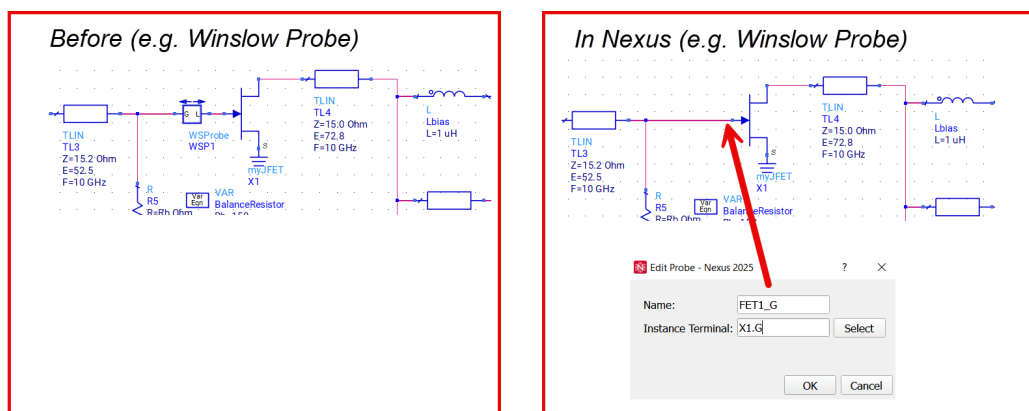


Figure 1. Schematics of (a) a Winslow probe inserted directly versus (b) virtual insertion via the user interface that preserves LVS (layout-vs-schematic) integrity

¹ Keysight internal research into RF simulator architecture evolution.

Traceability via “performances”

Simulation reproducibility is a long-standing challenge. “Performances” capture settings, parameters, filters, and optimizations into reusable, sharable profiles — mirroring the reproducibility of compliance tests in measurement instruments.

Decoupling analyses from tasks

By separating *analysis* (e.g., S-parameters, envelope) from *tasks* (e.g., sweeps, optimization), simulation becomes more modular (see figure 2), efficient, and easily parallelized — unlocking significant performance gains.

Unlocking 10× faster optimization

Traditional algorithms struggle with global optimization across multi-band, multi-technology designs. Multi-thread parallel execution and new optimization algorithms can deliver order-of-magnitude speed improvements.

Flexible licensing and modular updates

RF teams increasingly need rapid access to simulator updates. A modular simulator with flexible licensing allows immediate use of new features — without disruptive relicensing or platform updates.

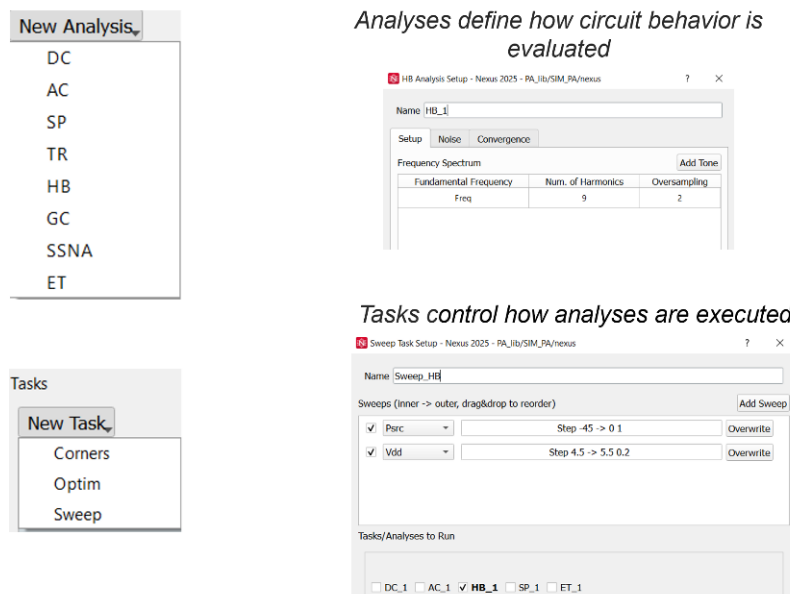


Figure 2. Separation between analyses and tasks in the simulator user interface makes simulation modular, efficient, and easily parallelized — unlocking significant performance gains

A New Vision: Simulation Inspired by Measurement

The future of RF simulation requires more than incremental improvements in speed or interface tweaks. It requires a fundamental rethinking of what a simulator is and how engineers interact with it.

Traditionally, simulators have been rigid, black-box tools — powerful engines that lock away valuable intermediate data and restrict engineers to workflows dictated by the software vendor. Keysight's next-generation approach reframes the simulator as a measurement instrument: modular, portable, automatable, and extensible.

This shift has several key advantages:

Programmatic control

Instead of relying solely on graphical user interfaces, engineers gain direct control of the simulator through APIs and scripting languages such as Python.

- **Why it matters:** Workflows become fully automatable, repeatable, and sharable, much like test scripts in measurement instruments.
- **How it helps:** Engineers can bypass the GUI for headless execution, integrate custom optimization algorithms, or stitch in third-party tools—without lengthy vendor-led customization projects.

Separation of analyses and tasks

Current simulators often bundle “what to simulate” (analysis) with “how to simulate” (tasks). The new vision decouples these, making simulations modular and flexible.

- **Why it matters:** Analyses like S-parameters or harmonic balance can be reused in multiple tasks, such as sweeps or optimizations, without duplication.
- **How it helps:** This separation enables efficient parallelization, allowing multiple tasks to run concurrently on different analyses, resulting in significant speed improvements.

Traceability and reproducibility

Reproducibility is a long-standing challenge in simulation. The new platform introduces *Performances*: packaged, traceable sets of parameters, conditions, and specifications.

- **Why it matters:** Engineers can confidently reproduce a simulation run from weeks or months ago, ensuring consistency across projects and teams.
- **How it helps:** Like measurement test routines, Performances are shareable and reusable, enabling standardization of simulation results across organizations.

AI Readiness

The future of RF design will increasingly rely on AI-driven exploration and optimization. Exposing hooks for programmatic control makes the simulator “AI-ready.”

- **Why it matters:** AI models can be trained on simulation data, then interact directly with the simulator to propose, refine, and validate designs.
- **How it helps:** Engineers will be able to run natural-language queries, automate Design-of-Experiments (DoE) workflows, and integrate AI-driven surrogate models that cut simulation time by orders of magnitude.

Measurement-simulation symbiosis

Keysight's vision deepens the connection between simulation and measurement science. Just as measurement instruments are scriptable, extensible, and portable, the simulator follows the same philosophy.

- **Why it matters:** Engineers can transition seamlessly between measured and simulated data, closing the loop between design, verification, and validation.
- **How it helps:** This reduces reliance on approximations or guesswork and increases confidence in simulation results as accurate reflections of real-world behavior.

Portability and extensibility

By re-architecting the simulator as a modular platform, new features, algorithms, and integrations can be added without disrupting the entire workflow.

- **Why it matters:** Design teams can adopt updates incrementally, aligning tool evolution with project timelines.
- **How it helps:** Engineers gain faster access to innovations without waiting for full-platform upgrades or negotiating new licensing terms.

In short, the next-generation RF simulator is no longer just a calculation engine. It becomes an open, extensible instrument that engineers can embed into workflows, automate at scale, and pair with AI to explore design spaces faster and more thoroughly than ever before.

Enhancing Designer Productivity

While the architectural motives establish the foundation, the real value of a next-generation simulator comes from what designers can do differently, faster, or more effectively in their daily work.

By exposing more control, data, and automation hooks, the new platform turns pain points like debugging, optimization, and workflow customization into opportunities for efficiency. This section highlights practical ways the re-architected simulator directly improves productivity at the engineer's desk.

Python-driven extensions

Designers can now embed Python functions into simulation workflows, replacing dozens of manual equations with reusable SciPy functions (see figure 3). External optimizers can also connect directly to the simulator API.

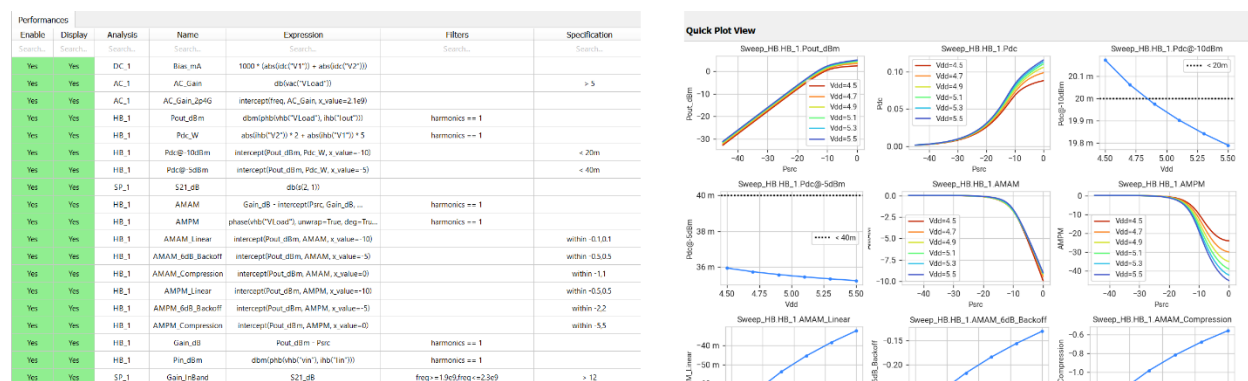


Figure 3. Python SciPy functions replace dozens of manual equations to process and display complex analyses results.

Smarter troubleshooting in layouts

Instead of guessing where simulation discrepancies originate, designers can visualize specific layout segments contributing to out-of-bounds results — dramatically reducing debug time.

Workflow flexibility and automation

An API-driven design model enables layouts and schematics to be represented as Python functions — making them directly modifiable by humans or AI. Researchers have already demonstrated AI surrogate modeling that reduces simulation data requirements by 1500× while capturing EM and multiphysics effects (see figure 4).

Parallel optimization and live visualization

Bringing optimization into RF Circuit Simulation Professional enables:

- Multi-platform compatibility.
- Real-time visualization of convergence progress.
- Automatic feedback into host design platforms.

This enhances yield analysis, prevents overdesign, and accelerates convergence (see figure 5).

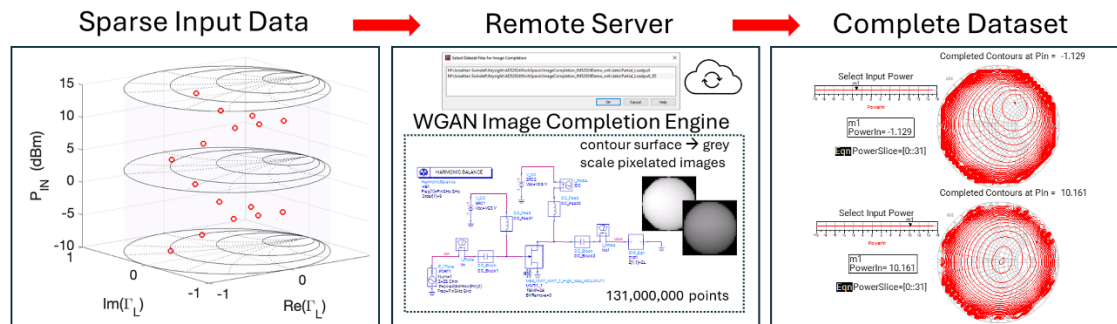


Figure 4. Load pull contours derived from a pretrained AI surrogate model to illustrate the speed up of surrogate modeling. It reduces simulation data requirements by 1500× while capturing EM and multiphysics effects. Source Jonathan Swindell, Baylor University. ¹

¹ Swindell et al., "Multi-dimensional Load- Pull Extrapolation for Accelerated Computer-Aided Design (CAD) Simulations," USNC-URSI NRSM, January 2025.

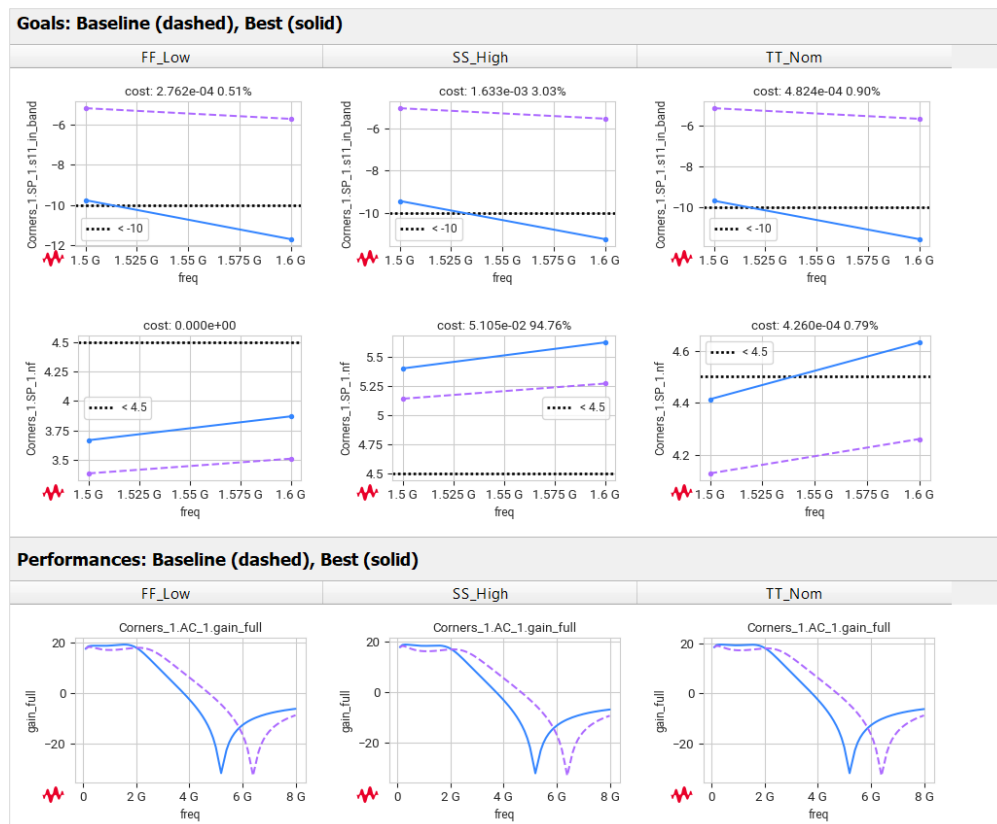


Figure 5. Parallel optimization of multiple performances enables live visualization of convergence progress and feedback of design effectiveness in meeting competing goals.

Future Possibilities for Automated RF Workflows

Beyond immediate productivity gains, the real potential lies in how this platform reshapes entire workflows. Programmatic control and modularity create an ecosystem where external optimizers, no-code tools, and AI can thrive, expanding simulation from a design-stage tool into a cornerstone of automated, intelligent RF development (see figure 6). This section explores near-term opportunities as well as visionary possibilities for how simulation will evolve in the coming years.

Optimizer ecosystem

An open simulator API fosters an ecosystem where external researchers and third parties can contribute optimizers, reducing dependence on vendor customization cycles.

No-code workflow sequencing

A visual, flowchart-style interface for simulation sequencing lowers the barrier for new users while enabling conditional execution and adaptive workflows.

AI-enabled simulation

Programmatic control will open the door in the future to:

- Natural-language queries for simulation runs.
- AI-driven design exploration during reviews or customer meetings.
- Better “virtual twins” for managing RF system complexity.

As these capabilities mature, simulation will move from a supporting role to the central nervous system of RF design, orchestrating optimization, verification, and exploration across tools and teams.

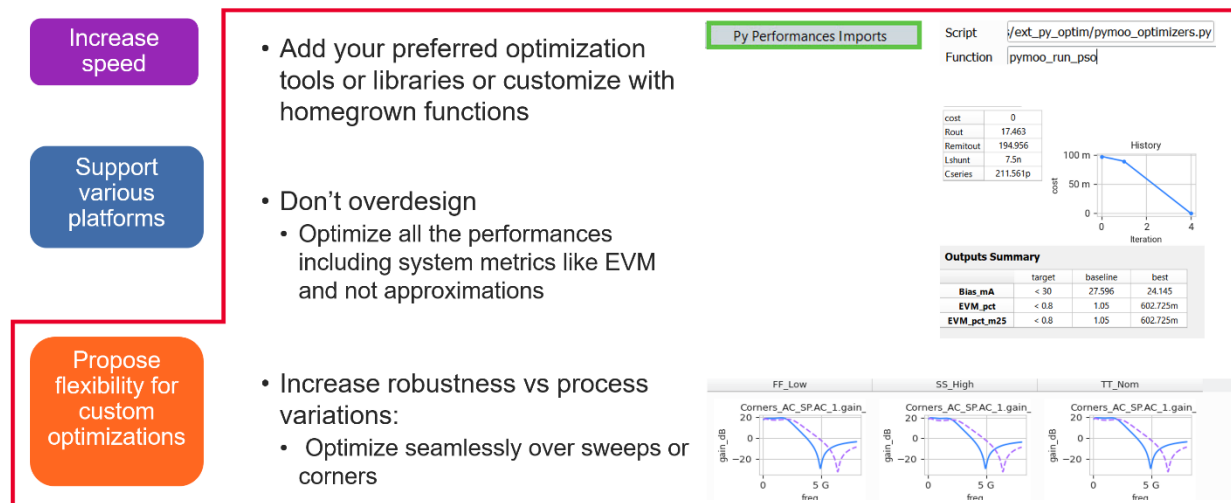


Figure 6. Programmatic control and platform modularity create an ecosystem for external optimizers, no-code tools, and AI algorithms, expanding simulation from a design-stage tool into a cornerstone of automated, AI enabled intelligent RF development.

Conclusion

The journey from rigid, vendor-defined simulators to a programmatically controlled, AI-ready platform represents more than just a technical upgrade — it's a fundamental shift in how RF design can be approached.

By reframing the simulator as a flexible, instrument-like engine, Keysight is addressing long-standing challenges in usability, speed, and integration while unlocking new pathways for automation and innovation by enabling:

- **Higher productivity** through Python integration, automation, and reusable performance.
- **Faster optimization** with parallelization and multi-objective convergence strategies.
- **Smarter workflows** through no-code sequencing and AI-assisted exploration.

This next-generation approach empowers design teams to achieve better first-pass success, reduce design cycles, and manage the growing complexity of modern RF systems.

To learn more visit:

[RF Circuit Simulation Professional | Keysight Keysight Advanced Design System](#)

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