

Creating Highly Efficient and Reliable mmWave Power Amplifiers

Multi-domain simulation with thermal analysis enables concurrent optimization of die, package, and PCB layout

Optimizing High-Frequency RF Power Amplifiers

Organization

- mmTron

Challenges

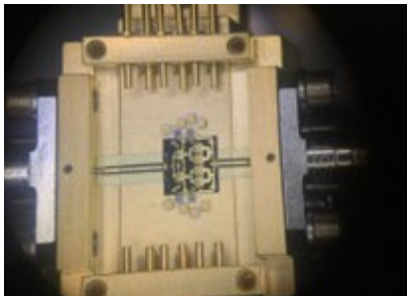
- High-power RF amplifiers commonly use multiple dies, giving up efficiency and size
- mmWave frequencies worsen losses and linearity
- Reducing die size increases thermal density and junction temperature, lowering reliability and service life
- Advanced III-V aging models are still scarce

Solutions

- Simulations with authentic waveforms, not sinusoidal frequency points, for modulated signals using PathWave ADS and PathWave RFPro
- Enhanced models in PathWave Device Modeling (IC-CAP) derived from GaN PDKs include thermal behavior, aging, and other features
- High-accuracy electromagnetic and electro-thermal simulation on a 48-core server

Results

- TMC211 single-die layout reduces area by 60% while efficiently delivering 50W of power
- Lower die temperatures enable 15-year life targets
- 97% first-pass design success across mmTron



mmTron, a Silicon Catalyst portfolio company based in Redwood City, California, specializes in designing high power, high linearity, yet efficient and reliable millimeter wave (mmWave) integrated circuits for advanced wireless and satellite communication systems. mmTron creates RF components in high-speed III-V processes, including GaAs, GaN, InP, SiGe, and RFSOI.

Dr. Seyed Tabatabaei founded mmTron in 2020 from his experience in RF test and measurement equipment circuit designs at Hewlett Packard, the birthplace of Keysight technology, and more recently, time at two other mmWave component design startups. mmTron's seven engineers use Keysight PathWave Advanced Design System (ADS) in a workflow with tools from Altium, Ansys, Cadence, and others.

The TMC211 is mmTron's latest 27-31 GHz power amplifier (PA). Its single-die GaN design delivers 50W power with 28% power-added efficiency (PAE), strong linearity, and a lowered operating junction temperature, which contributes to a higher mean time between failures (MTBF). Multi-domain electromagnetic (EM) and electro-thermal simulation capability in ADS and PathWave RFPro drives similar outcomes across mmTron's products.

Challenge: Deliver more power without compromises

Much of the history of engineering has been a collection of practical tradeoffs during a project. Designers choose a set of parameters critical to their application and incorporate those in a design using physically implementable components and techniques to the best of their abilities. Attention then turns to sub-optimizing, maximizing a few desirable parameters while keeping others within acceptable limits. Classical hand calculations or single-domain simulation perform sub-optimization well.

Most manufacturers optimize RF PAs for the obvious parameter: maximizing the power a PA can deliver, with a secondary emphasis on linear performance across the operating bandwidth. More output power means more input power from the DC supply. Adding in power losses due to inefficiency and dissipated power in the PA translates to elevated junction temperature, lower reliability, and a shortened lifespan.

With more power amplifiers heading into long life cycle wireless communication applications – like defense and SATCOM – manufacturers have turned to multi-die PA solutions to spread power density across the package. Interconnect losses between dies cut power efficiency, linearity can be harder to control, and mmWave frequencies make effects more pronounced. Package size can also be a concern in aggressive SWaP-C (size, weight, power, and cost) environments.

Tabatabaei, shown in the lab in Figure 1, and his engineers asked: what would mmTron need to do to deliver more power with a single-die PA while still achieving linearity and SATCOM levels of reliability?

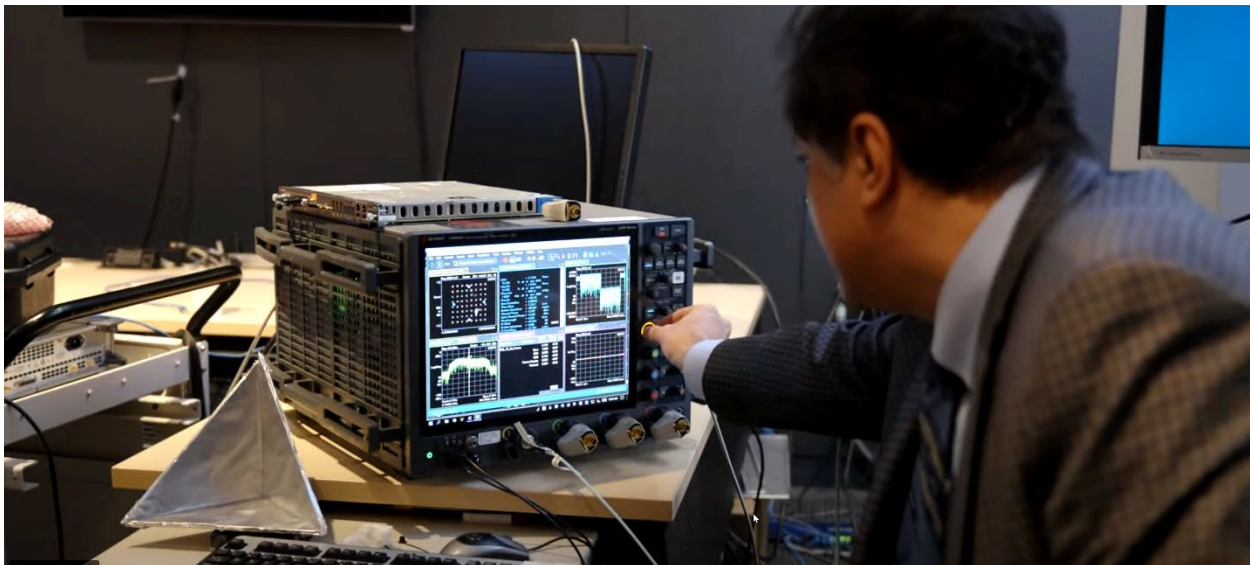


Figure 1. mmTron founder Dr. Sayed Tabatabaei running tests in a lab

III-V processes like GaN provide the power density customers want. Arriving at a fully optimized design, unlocking the power potential while maintaining excellent linearity on a single die at a lower operating temperature, would require much more sophisticated behavioral models and simulation to account for cross-domain effects. “We knew going into the TMC211 design that thick metalization and close coupling between PA stages would create resonances making accurate EM simulation difficult,” says Tabatabaei. A coordinated electro-thermal simulation would also be crucial for optimizing the design.

Solution: Authentic waveforms and enhanced models in multi-domain simulations

Pushing the performance of RF components and system design calls for a suite of EDA tools for various tasks. Tabatabaei was deeply familiar with ADS, but some of mmTron's engineers were less familiar with the Keysight RF EDA environment. mmTron adopted Keysight PathWave ADS as the linchpin of its workflow, and its teams now see the advantages. "ADS enormously speeds up our product development because we can copy templates and set-ups quickly and start a new design," says Tabatabaei.

Templates are essential, but many EDA vendors offer templates. Another reason brought Tabatabaei to select ADS. "I definitely place a high value on Keysight's people," Tabatabaei continues. "The knowledge and skills they bring around ADS help us catch more issues earlier and work through situations like scripting, integration, and more that are extremely valuable in our mmWave RF component design efforts."

mmTron RF EDA tool stack

Workflow Step	EDA Tools
RF Device Modeling	Keysight PathWave Device Modeling (IC-CAP)
RF Circuit Design and Simulation	Keysight PathWave ADS
RF System Modeling and Simulation	Keysight PathWave System Design
3D Electromagnetic Simulation	ANSYS® HFSS™, Dassault Systèmes CST Studio Suite®, Keysight PathWave RFPro
Electro-Thermal Simulation	Keysight PathWave ADS Electro-Thermal Simulator
PCB Design and Layout	Altium Designer®, Cadence Allegro®

The next big decision for mmTron was a commitment to using authentic waveforms in ADS simulations. The alternative uses sinusoidal stimulation at several points across the bandwidth, then designing in excess margin, but the outcome is far less certain to predict as conditions change. "There are many PA subtleties that only appear under modulated signals," states Tabatabaei. "How the signal phase changes between stages, memory effects, interactions with capacitor values and placements, and power consumption all depend on modulation."

Customers are approaching mmTron with questions such as how crest factor and peak-to-average power ratio (PAPR) look in specific modulation scenarios. "Our core competence is using design and layout steps for optimizing the PA structure to provide the best performance in a modulated environment, and we have a lot of scripts written to help do that," says Tabatabaei. For example, Keysight assisted mmTron in developing ADS scripts to help keep PA power delivery constant as modulation varies.

Figure 2 is an example of the mmWave die structures mmTron creates using ADS, showing the thick metalization between some of the circuit elements.

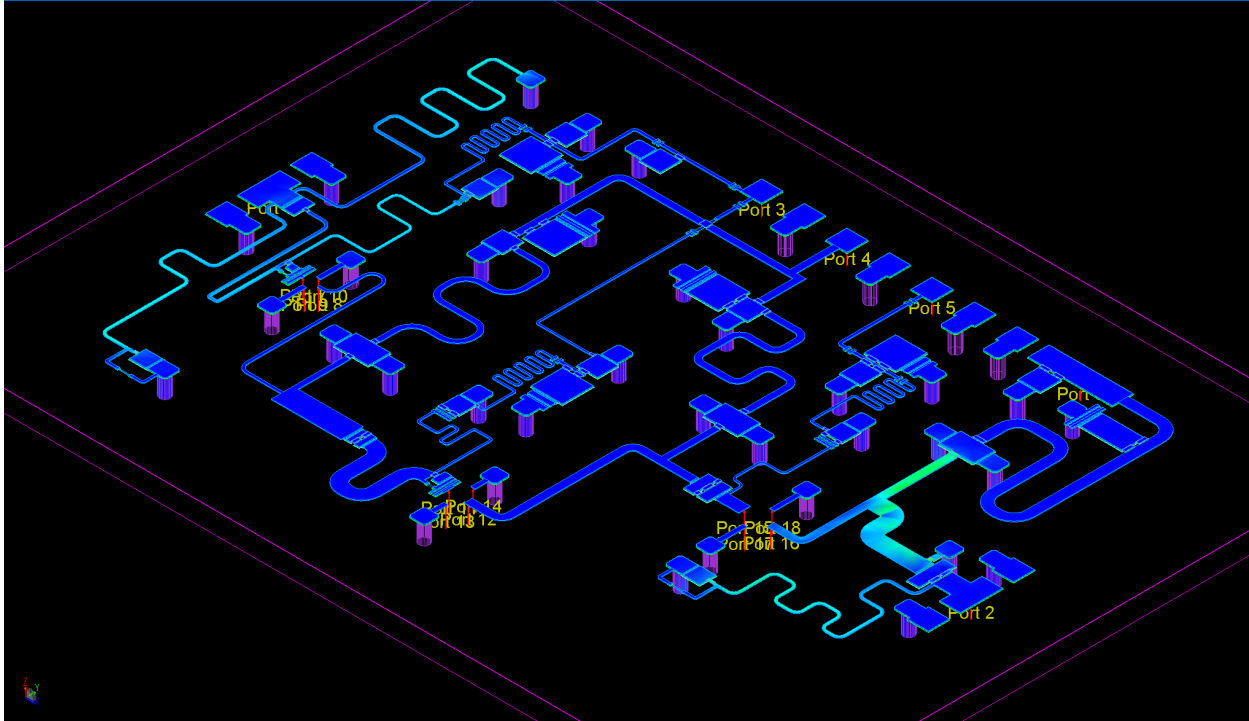


Figure 2. Rendering of a mmTron power amplifier ready for EM and thermal simulation in Keysight PathWave ADS

Accurate simulation results and, ultimately, the quality of MTBF predictions also depend strongly on the robustness of behavioral models. Most commercially available process design kits (PDKs) for the GaN technology used in the TMC211 concentrate on functional performance, not aging. “We need to simulate drift, gate leakage, and more aging detail to predict MTBF accurately,” shares Tabatabaei. “We obtained DARPA-funded GaN models from a university and made substantial customizations reflecting the SATCOM environment, including different specifications for low-earth orbit (LEO) or geostationary orbits (GEO).”

Thermal modeling works hand-in-hand with EM modeling for coordinated simulation in ADS using the native EM simulator and the electro-thermal extension in a single, easy-to-use interface without layout conversions. Layout loops between a die, its package, and the printed circuit board (PCB) can pose issues. mmTron used ADS’s extensive stability analysis capability to optimize the die and package design together, along with a recommended PCB layout.

Load-pull analysis is a good example where advanced multi-domain simulation enhances accuracy. mmTron drew on years of experience with many ADS templates and some insight from Keysight customer success engineers in creating their custom solutions.

“We’re in a high-touch environment where we work closely with our customers,” says Tabatabaei. Often this extends beyond developing and running simulation scenarios on mmTron’s 48-core EDA server to performing corroborative measurements describing set-ups and test and measurement equipment for verification. mmTron can share ADS files or encrypted PDKs with mmTron enhancements for customers to run their own simulations. Whether customers can use a standard product once seeing how it simulates in their context or whether they need a specially designed derivative to meet requirements, mmTron can meet the need.

Results: Creating state-of-the-art PAs faster

mmTron captures the benefits of using PathWave ADS innovatively in three areas. The first is creating the state-of-the-art TMC211 with what Tabatabaei describes as “unheard-of performance,” citing one key specification: 23W of linear power at a noise power ratio (NPR) of 19. Figure 3 shows a screenshot from the TMC211 preliminary datasheet (subject to change). According to Tabatabaei, Its single die is 60% smaller than competing multi-die amplifiers delivering less power.

Electrical Performance : Vdd = 28 V, Vgg = -3.7 V, TA = 25 °C, F = 29 GHz				
	min	Typ	Max	Units
Frequency	27		31	GHz
Gain		17		dB
Return Loss		10		dB
Psat		47		dBm
PAE		28		%
Bias Voltage		28		V
Bias Current		1700		mA

Figure 3. Electrical performance specifications of the mmTron TMC211 27-31 GHz power amplifier MMIC

Another benefit is a hybrid business model for mmTron. Tabatabaei says his teams have been able to turn derivative product designs for specific customer requirements in less than a month. mmTron is experiencing a growth spurt with four times the number of customer engagements during the first quarter of 2023 compared to prior years. Some of these customized designs may be spun back out as standard products if there is demand. The TMC211 began its journey as a derivation from a prior 25-29 GHz design, the TMC2111, done for a specific program before being standardized as an off-the-shelf product.

Finally are the internal metrics. Tabatabaei shares that his teams have a 97% first-pass success rate across all standard or custom product designs executed in ADS since mmTron’s inception. This success rate gives customers a high confidence level in mmTron, allowing mmTron to engage in more projects and scale their engineering resources effectively. “We’re able to plan our standard product roadmap two years out while still keeping the flexibility to grab customization opportunities where they make sense,” says Tabatabaei. He adds his team is branching out from PAs and RF front-ends to low-phase-noise oscillators and extremely broadband mixers with similar optimized performance and life cycles.

“I definitely place a high value on Keysight’s people. The knowledge and skills they bring around PathWave ADS help us catch more issues earlier and work through situations like scripting, integration, and more that are extremely valuable in our mmWave RF component design efforts.”

Dr. Sayed Tabatabaei, Founder and CEO, mmTron

mmTron is also exploring the emerging sub-THz frequency space with customers, preparing for when process technology, test and measurement equipment, and viable economic volumes align.

Looking ahead: A single design cockpit

Tabatabaei suggests Keysight RF EDA tools cover the right design and simulation areas and exchange data cleanly. However, it would be even better if they all came together in a single design “cockpit.” For example, ADS and PathWave System Design currently launch as separate applications. “Shouldn’t PathWave System Design launch directly from the ADS user interface,” he muses. Transistor counts are rising as RF component complexity grows. mmTron has leveraged an affordable layout versus schematic (LVS) checking tool combined with extensive scripting in ADS, and better integration would help.

Learn more about mmTron and its mmWave RF signal chain products at:

www.mmTron.com

For more information on these Keysight RF EDA solutions, please visit:

[PathWave Advanced Design System \(ADS\)](#)

[PathWave RFPPro](#)

[PathWave ADS Electro-Thermal Simulator](#)

[Keysight EDA Software: First by Design](#)

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