

mmWave RF Driver Amplifiers with Better Engineered Tradeoffs

Robust models and Winslow probe stability analysis help deliver balanced gain, output power, and bandwidth.

Wider, Flatter, Quieter mmWave RF Amplifiers

Organization

- Marki Microwave

Challenges

- Customers seeking optimized LO driver performance in RF signal chains with Marki mixers
- Create a stable two-stage amplifier design in an advanced semiconductor process with many behavioral unknowns
- Develop an effective workflow for accurately characterizing mmWave amplifier designs under tight schedules, reducing re-spins

Solutions

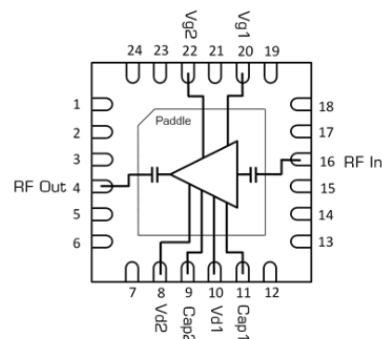
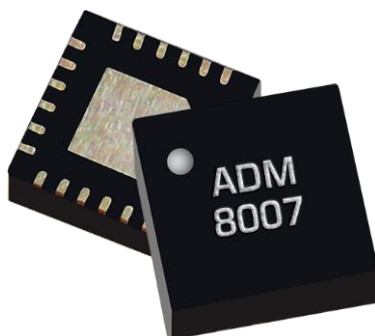
- Created an accurate design workflow based on PDK models enhanced with measurements using PathWave ADS and PathWave RFPro
- Sought balanced performance between gain under compression, output power, and bandwidth in the context of the mixer drive application
- Leveraged circuit and electromagnetic simulation with measurement informed transistor models and Winslow probe stability analysis to increase first-pass success without fabricating and testing parallel variants

Results

- ADM-8007PSM design hit gain and output power targets with suitable bandwidth
- Gained vital experience in merging RF driver amplifier and mixer modeling and simulation philosophies for improving design productivity

Marki Microwave, based in Morgan Hill, California, is a recognized industry leader in high-frequency RF mixers and filters. Thanks to its engineering-driven reputation, with some 15 engineers including highly experienced and recent-graduate talent, customers asked if they could supply more complementary RF components. Since 2018, Marki teams have extended a lineup of mmWave RF driver amplifiers for pairing with their mixers, in a workflow with Keysight PathWave Advanced Design System (ADS).

The ADM-8007PSM is Marki Microwave's latest 2 – 40 GHz surface mount amplifier with +23 dBm of extremely flat, low noise output power and a very low 1 dBm drive level needed to saturate the output. It comes in a 4 x 4mm, 24 lead package and operates on 5VDC power. Advanced EEHEMT non-linear transistor modeling, circuit and electromagnetic (EM) co-simulation, and stability analysis in ADS and PathWave RFPro brought Marki's mmWave driver amplifier technology to a new level.



Challenge: Reaching stability with minimized prototyping

The origin story of the ADM-8007PSM is a tale of the importance of design for context (DfC) in complex RF systems. Customers asking Marki for help designing a driver amplifier for its mixers is no accident. Before DfC, RF system designers had the chore of choosing components for a spot in the signal chain based on generic data sheet parameters selected by the manufacturer. System-level simulations often sampled a few frequency points, hoping no interpolative surprises lurked between points.

Higher frequencies, wider bandwidths, and complex modulation shattered that thinking. The central theme of DfC is models and simulations need to reflect how RF components work in an application – exposing interactions between components, packaging, circuit board layouts, and cross-domain effects.

“Customers have significant input to requirements, but most of our products are specified and developed by the engineers who will make the tradeoffs that look the best,” says Doug Jorgesen, VP of Systems and Applications at Marki Microwave. The objective for the ADM-8007PSM was designing a driver amplifier that would deliver optimum performance from the local oscillator (LO) amplifier-mixer combination, shown in Figure 1, placed in a typical mmWave signal chain.

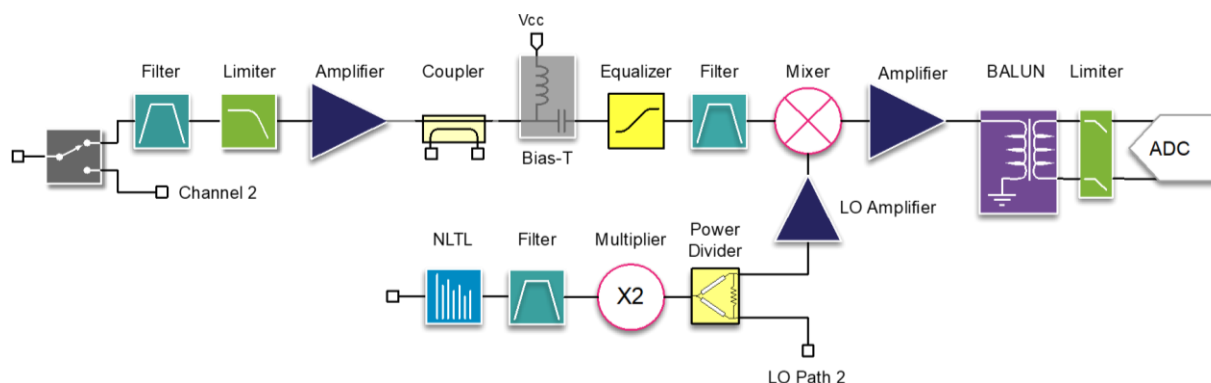


Figure 1. Elements feeding a mmWave mixer can influence its apparent performance in RF system applications

“The biggest question mark on the ADM-8007PSM was doing this two-stage design to hit the gain target at high frequency across a wide bandwidth in an unfamiliar semiconductor process in a package with unknown bias circuits, and have it all end up stable,” continues Jorgesen. High power and efficiency weren’t primary concerns; Jorgesen says getting more than 50% efficient on a super-broadband design (more than an octave wide) is hard. He also says Marki does not do extensive load-pull analysis in most cases, partly because the intended driver amplifier load is known – a Marki mixer – and partly because efficiency isn’t an optimization criterion for the design.

In their prior workflow, Marki engineers would use their experience to guess the most sensitive parts of a driver amplifier, create perhaps four or five or more candidate designs with varying parameters, build them all out and take physical measurements, and pick the one they liked best to proceed. “If our guesses were correct, and parts didn’t oscillate due to layout or bias issues, we’d still end up with up to three spins to reach a finished amplifier product,” Jorgesen observes.

What Jorgesen describes is an ideal use case for circuit-EM co-simulation using ADS, doing the necessary parameter exploration virtually and improving the chances of first-pass success at fabrication.

Solution: Modeling parasitics, bias, and packaging

Consider a non-trivial point of concern in simulations matching real-world measurements for an advanced high-frequency semiconductor process with complex non-linearities: the behavioral models must be highly detailed. Marki Microwave brings extensive modeling experience to bear on the opportunity.

“Foundry process design kits (PDKs) are a starting point for us,” explains Jorgesen. “We’ll take engineering samples from the foundry, measure S-parameters from those very carefully, and use those results to either modify the PDK they provide or develop a standalone model for our needs.”

The next step is embedding the robust S-parameter measurements within Marki’s passive structure modeling. More from Jorgesen: “It’s pretty hard to make a non-linear transistor model, but it’s relatively easy to make a linear *transition* model taking the measured S-parameters and fitting those in.” Marki also uses a few hacks to improve parasitic representations in the structure, like adding bias-variable capacitance or inductance, or even negative capacitance, which most foundries say is a no-no in PDKs.

Marki also invested considerable effort in choosing the framework for the transistor models. “We went pretty deep with the Keysight transistor team, David Root and his people, to understand the best transistor model for us to use,” Jorgesen shares. Those discussions led Marki’s teams to the EEHEMT transistor models in ADS. “We ended up with the S-parameter embedding, and we can then play with other elements to make scalable models for studying specific aspects of the transistors in the amplifier.” Some more elements Marki uses for its model refinements and enhanced characterization:

- Noise figure profiles from straightforward noise measurements.
- Self-heating and current change under drive, secondary effects requiring attention.
- Bias voltages varied across simulation scenarios for key performance metrics.

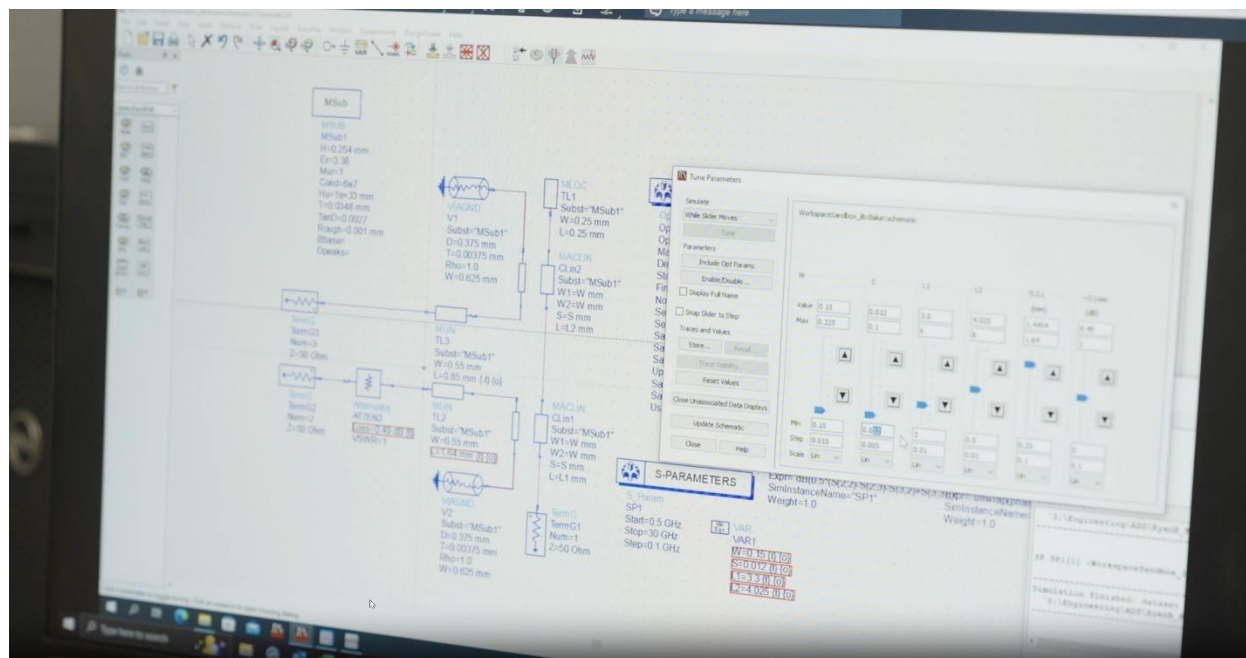


Figure 2. S-parameters embedded in a passive structure model for a Marki Microwave amplifier design in ADS

Detailed models also inform packaging, which Jorgesen terms “an obsession” for Marki. “It’s easy to miss inductance or capacitance of leads, and sometimes it’s hard not to double-count,” he adds. The advanced 4 x 4mm surface mount package for the ADM-8007PSM underwent several modifications to perform while not oscillating at up to 40 GHz. Marki also carried models and simulations through an entire PCB layout for providing the ADM-8007PSM in a connectorized module, the EVB-ADM-8007P, shown in Figure 3. (Marki’s datasheet indicates: “The IC is mounted 180° rotated to accommodate standard left to right input to output signal flow.”)

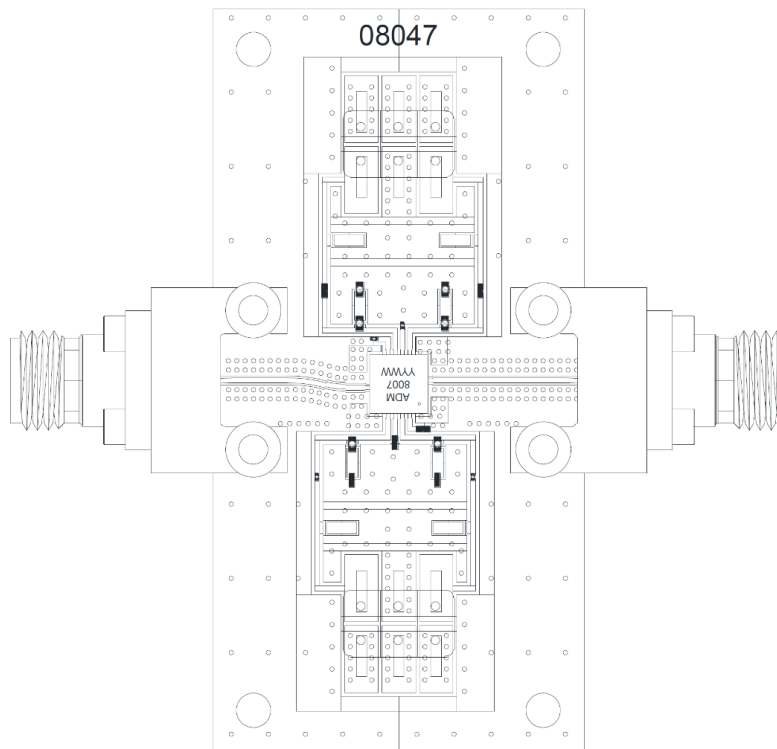


Figure 3. A Marki Microwave ADM-8007PSM on its PCB in outline drawing for the EVB-ADM-8007P module

Marki’s mixer EDA workflow used several legacy layout and EM analysis tools from different vendors. When its driver amplifier projects started, Jorgensen says Marki amplifier engineers were already savvy with ADS and RFPPro from their experience before joining the company – it’s now one of their hiring criteria. Moving to the ADS environment was a natural choice for Marki even before discovering Keysight’s level of support for advanced transistor models beyond other RF EDA tools.

Another capability in ADS proved indispensable: Winslow probes, enabling comprehensive stability analysis of the ADM-8007PSM. “If you don’t compensate for parasitics correctly, you end up with a low pass filter and don’t hit the bandwidth target, or you overshoot, and you get an oscillator,” Jorgensen quips. Winslow probes (or WSProbes, as their author, Dr. Thomas Winslow, refers to them) are non-invasive, not affecting amplifier performance. They collect a wide range of data accurately, even with feedback around the probe. In a single ADS simulation, designers can see multiple stability metrics such as Bode’s Return Difference (internal), NDF (external), Driving Point Admittance, and Ohtomo loop gain, saving time over manual testbenches and finding issues physical probing would miss.

Results: Predictable first-pass performance

Three performance targets defined the ADM-8007PSM design: gain under compression, output power, and bandwidth. Jorgesen says they reached the gain and power targets and came very close to their anticipated bandwidth target, with physical measurements on the fabricated part matching simulations. Figure 4 shows output compression curves with nominal, high, and low bias.

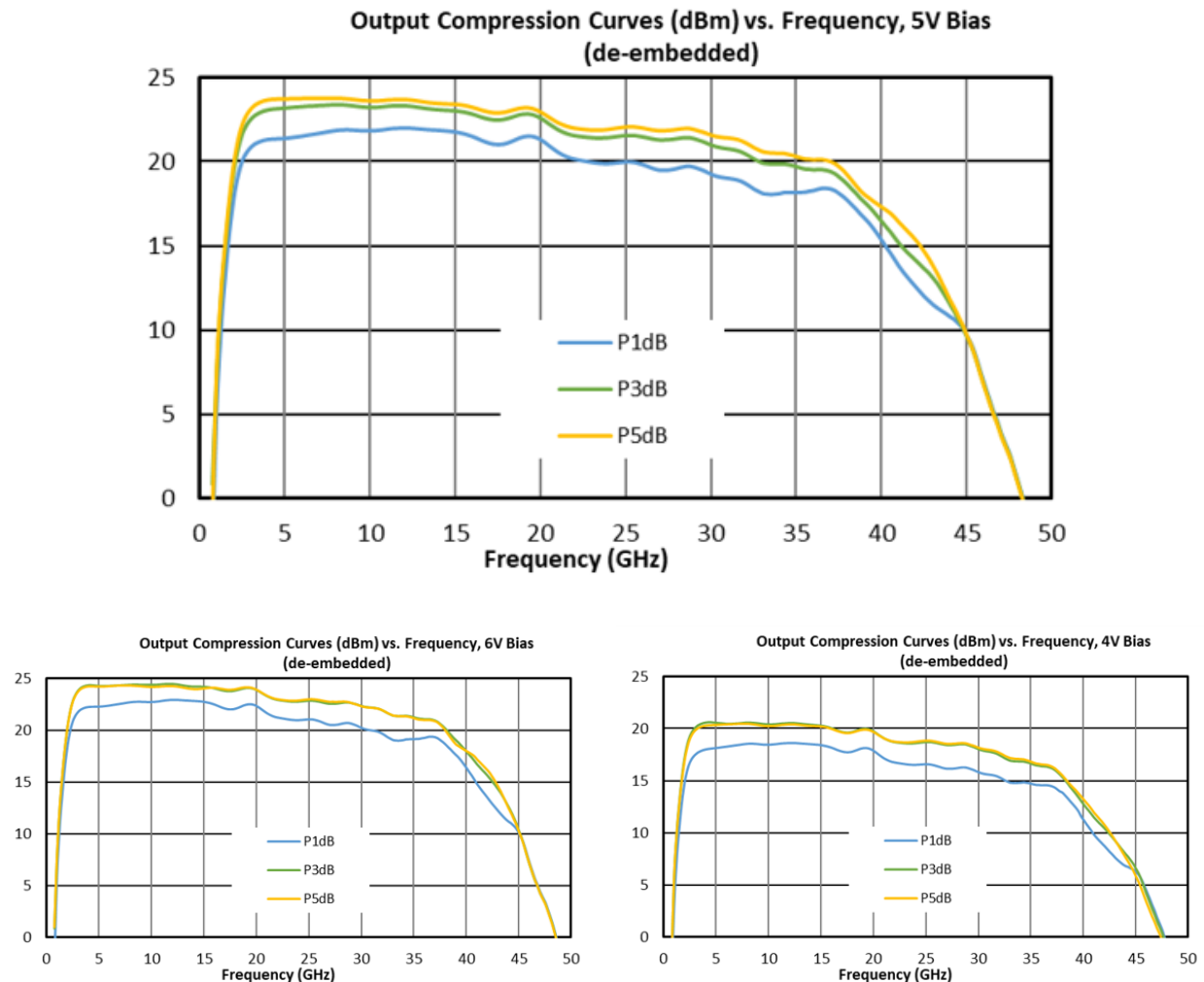


Figure 4. Gain under compression versus bias voltage results for the ADM-8007PSM driver amplifier

Most importantly, using ADS, Marki achieved these results on the first pass of a fabricated part. “When we’re very careful with our design and do a full modeling work up on an amplifier in PathWave ADS, spending extra time on different transistor models, we can get through with one variant,” Jorgesen observes. Figure 5 shows more performance metrics evaluated versus bias voltage.

“Having a high-performance driver amplifier is opening new conversations,” sums up Jorgesen. Making better tradeoffs faster, coupled with first-pass success, means Marki can now create more breadth in its product catalog, helping customers with more choices for optimizing their system designs.

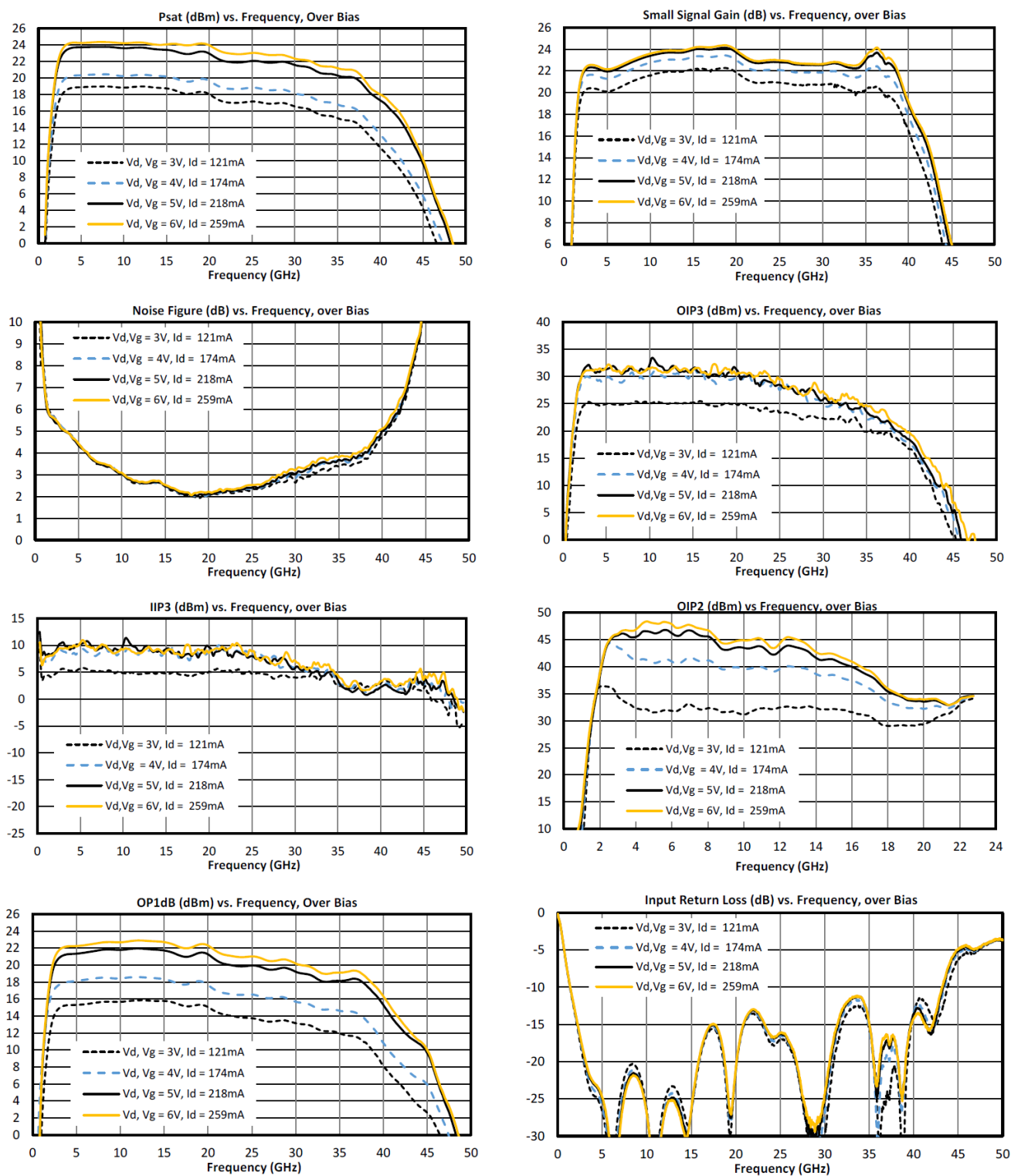


Figure 5. Evaluating bias voltage effects on key performance metrics of the ADM-8007PSM driver amplifier

“When we’re very careful with our design and do a full modeling work up on an amplifier in PathWave ADS, spending extra time on different transistor models, we can get through with one variant.”

Doug Jorgesen, VP of Systems and Applications, Marki Microwave

Looking ahead: Leveling up with AI-assisted design

With diode-based products running up to 140 GHz, thanks to proprietary non-linear, physics-based models, pushing transistor-based products higher is the next frontier for Marki. Conservative engineering practices say they’ll do as much as possible with existing semiconductor processes while learning about model detail to help transition to the next levels. Table-based models coupled with advanced EM solvers are a likely next step as Marki’s mixer and amplifier modeling philosophies start to merge.

Marki is also excited about the possibilities for AI-assisted design. They’re working on using 3D EM simulations to train a neural network to predict the effects of geometry changes in RF couplers. For driver amplifiers, they would like to see more user-friendly, intuitive experiences for parameter extraction and model creation from measurement data with native neural network training in ADS.

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

www.MarkiMicrowave.com

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

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

[PathWave RFPro](#)

[PathWave ADS Electro-Thermal Simulator](#)

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

[General Circuit Analysis Using the WSProbe](#)

All figures courtesy of Marki Microwave, Inc.

Keysight enables innovators to push the boundaries of engineering by quickly solving design, emulation, and test challenges to create the best product experiences. Start your innovation journey at www.keysight.com.



This information is subject to change without notice. © Keysight Technologies, 2023, Published in USA, June 7, 2023, 3123-1446.EN