H2ID Heatmap Wizard

Interactive Design-Space Exploration for RF Power Amplifiers

The H2ID Heatmap Wizard provides a visual and interactive approach to RF power amplifier design. Rather than evaluating a single operating condition at a time, the wizard exposes the entire H2ID design space and shows how performance varies across it. The wizard allows engineers to explore hundreds of candidate operating points simultaneously and rapidly identify the most promising regions of the design space.

Using color-coded heatmaps, designers can instantly identify regions of high efficiency, favourable power factor, high output power, acceptable voltage stress, desired conduction angle, or reduced knee interaction and degradation. Practical device constraints can be applied and modified in real time, allowing immediate exploration of design trade-offs.

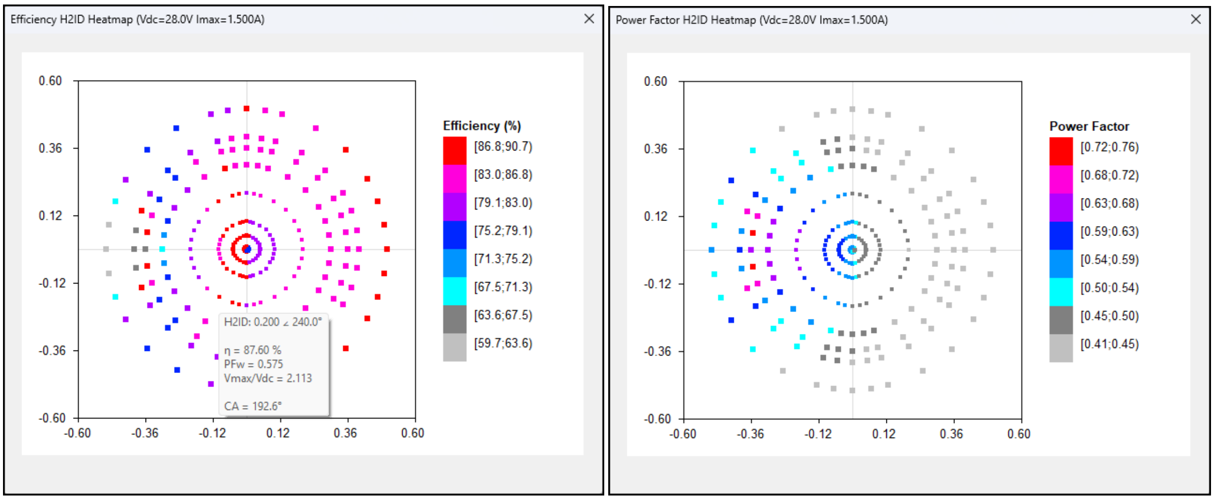

Figure 1. Efficiency and Power Factor heatmaps. Tooltips are shown when the mouse is moved over a *H2ID* operating point. The tooltip shown is with the transistor knee ignored.

The H2ID Heatmap Wizard enables users to:

- Visualize the complete H2ID design space.
- Identify operating regions that provide the best compromise between efficiency, power output, power factor, voltage stress and current utilization without pushing into the transistor knee boundary.
- Apply realistic transistor operating constraints.
- Inspect individual operating points in detail.
- Compare multiple operating points simultaneously.
- Display the dynamic load line and list the harmonic load terminations associated with each inspector.
- Show the range of maximum currents (I_{max}) over which the targeted performance is achieved for each inspector.
- Display the harmonic terminations associated with the inspectors on a Smith chart, including the termination at the targeted maximum current and those along the valid I_{max} range.
- Perform real-time "what-if" analysis using interactive slider controls.

The wizard maps each H2ID vector in the design space to the associated normalized intrinsic output current waveform. For each H2ID operating point, a complementary normalized voltage waveform is synthesized to maximize waveform efficiency. The voltage waveform is limited to the fundamental, second, and third harmonics, and negative resistance is not permitted. With the waveforms defined, the intrinsic normalized harmonic load impedances are known.

The output power is determined by the selected complementary waveform pair, the associated power factor, the targeted peak current and the applied *dc* voltage. The transistor knee then introduces an important practical trade-off between output power and efficiency. At maximum output power, efficiency is seriously degraded by the transistor knee. As the targeted peak current is reduced, output power decreases, while efficiency approaches the waveform efficiency.

When a specific transistor is targeted, the normalized current waveform is scaled to the targeted peak level, while the voltage waveform is scaled to just touch the knee boundary with the *dc* voltage specified. With the scale factors known, the associated intrinsic harmonic load impedances can be calculated. If a transistor model is available or the parasitic output side components are known, the intrinsic load impedances can be mapped to the external reference plane. To summarize:

H2ID vector → Normalized intrinsic output current waveform → Normalized complementary voltage waveform → Current scaled to specified peak → Voltage scaled to touch the knee boundary for the specified *dc* voltage → Scale factors known → Intrinsic harmonic load impedances known → External harmonic load impedances obtained.

Up to six operating points in the H2ID vector space can be inspected simultaneously, allowing direct comparison of efficiency, power factor, output power, conduction angle, harmonic load impedances, voltage stress, current utilization, knee factor, and dynamic load-line behaviour. Persistent inspectors allow selected designs to be retained while device parameters and design constraints are changed, making before-and-after comparisons immediate. The inspector operating points and window positions can be cleared by using the option provided when the heatmap and device parameters are specified.

The knee boundary can be a line (constant knee resistance) or a curve. Up to eight points can be specified to define the curve. Linear interpolation is used between adjacent points. The points can be positioned to obtain a tight piecewise-linear fit to the transistor knee characteristic. Operation beyond the knee boundary, including waveform clipping and compression, is not considered. The Wizard determines the maximum unclipped operating condition. The saturated power for a Class-B-like or Class-F-like operating point is typically a few decibels higher than the maximum unclipped output power calculated in the wizard.

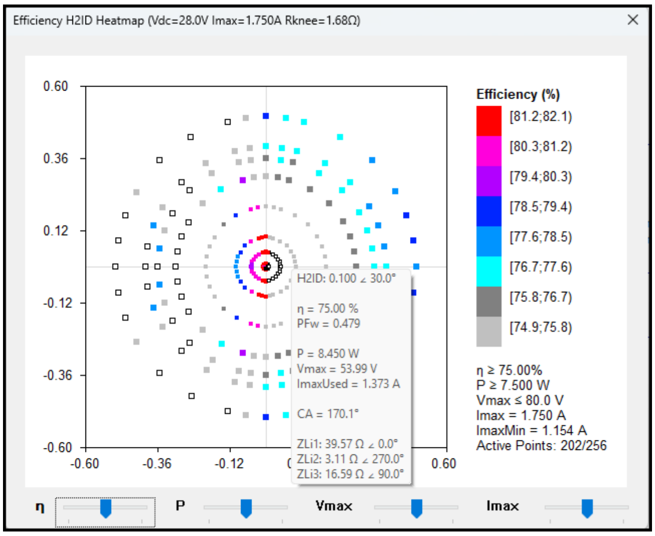

Figure 2. The effect of the transistor knee on efficiency is shown here. Constraint sliders allow acceptable efficiency, power, voltage and current limits to be adjusted interactively.

The dynamic load lines displayed in the inspectors provide visual validation of the waveform synthesis. The load line remains outside the knee region and touches the knee boundary at the point implied by the waveform solution. The dynamic load line plot therefore allows the designer to verify both the synthesized waveform behaviour and the associated transistor constraints immediately.

A cascade network consisting of up to three shunt capacitors and three series inductors is used to map the intrinsic load impedances to the external reference plane. In the Ampsa Amplifier Design Wizard, the mapping can be done by using power parameters. Other than linearity, no assumptions are made when the power parameters are used (internal feedback and resistive losses are allowed).

Instead of asking only what load impedance satisfies a particular design condition, the H2ID Heatmap Wizard allows the designer to see which regions of the available design space satisfy the required efficiency, power, voltage and current constraints, and then obtain the harmonic terminations required to realize a selected solution.

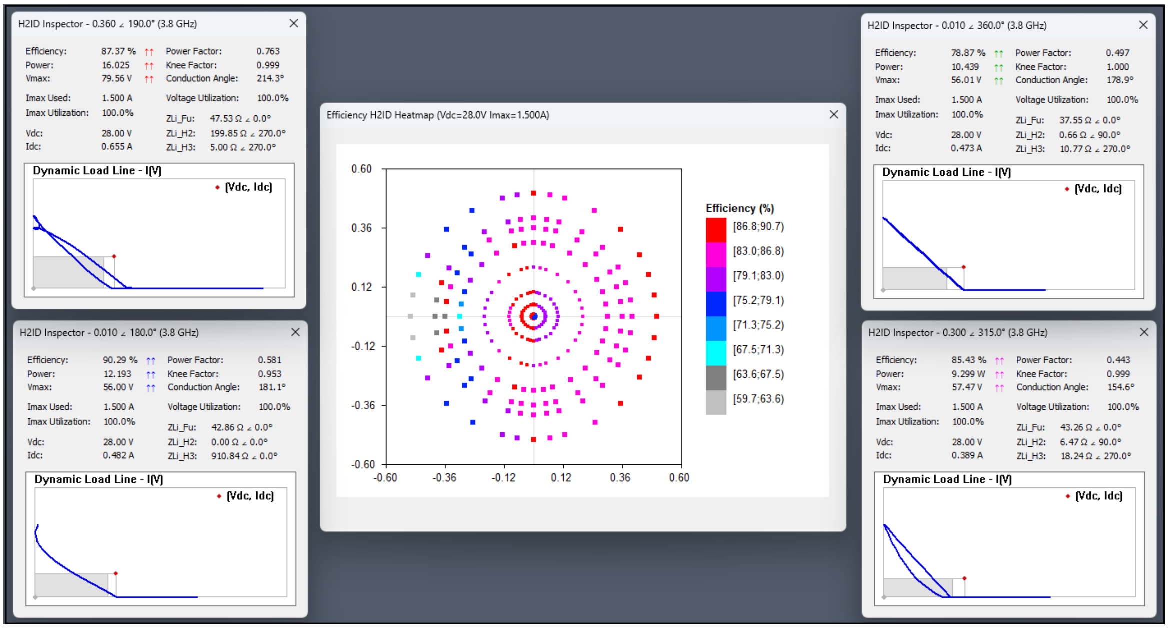

Figure 3. Inspectors can be opened for up to six operating points in the *H2ID* design space. The knee was ignored here. The red dots show the *dc* operating points. The shaded rectangles show the output power relative to the *dc* power.

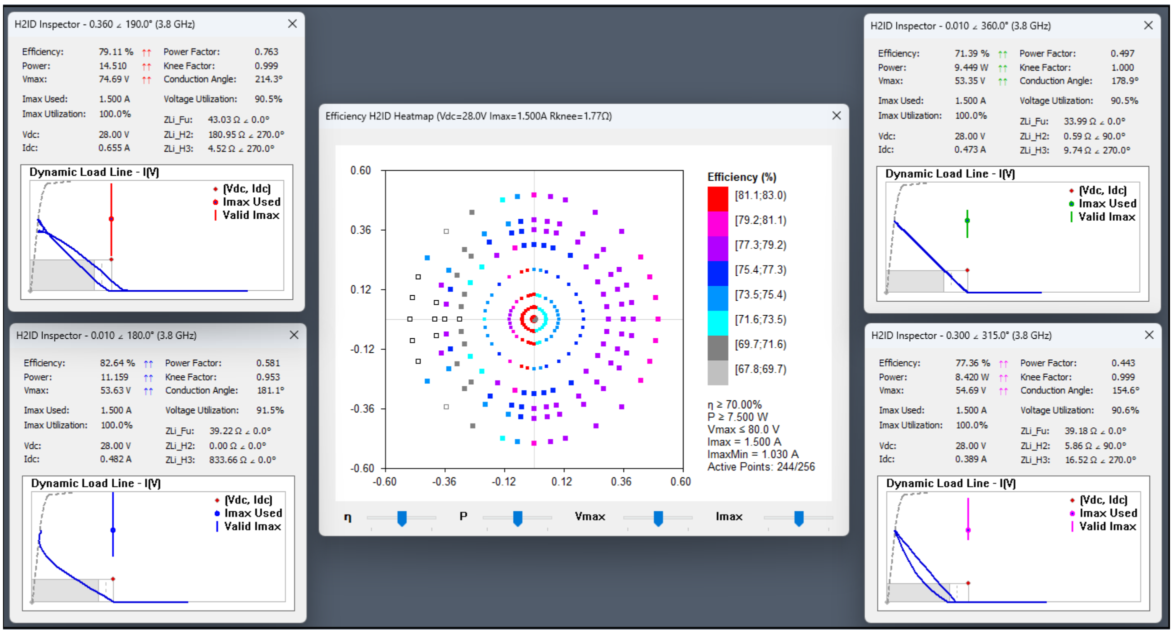

Figure 4. The same inspectors as in Figure 3 are shown, but with the degrading effect of the knee included. The dashed grey lines show the knee boundary. The maximum-current (I_{max}) ranges over which the efficiency and power targets are met are shown in the inspector colours. When the specified targets are not met, the I_{max} lines turn grey. The up arrows displayed in the inspector colour change to darker down arrows when performance is outside the specified target.

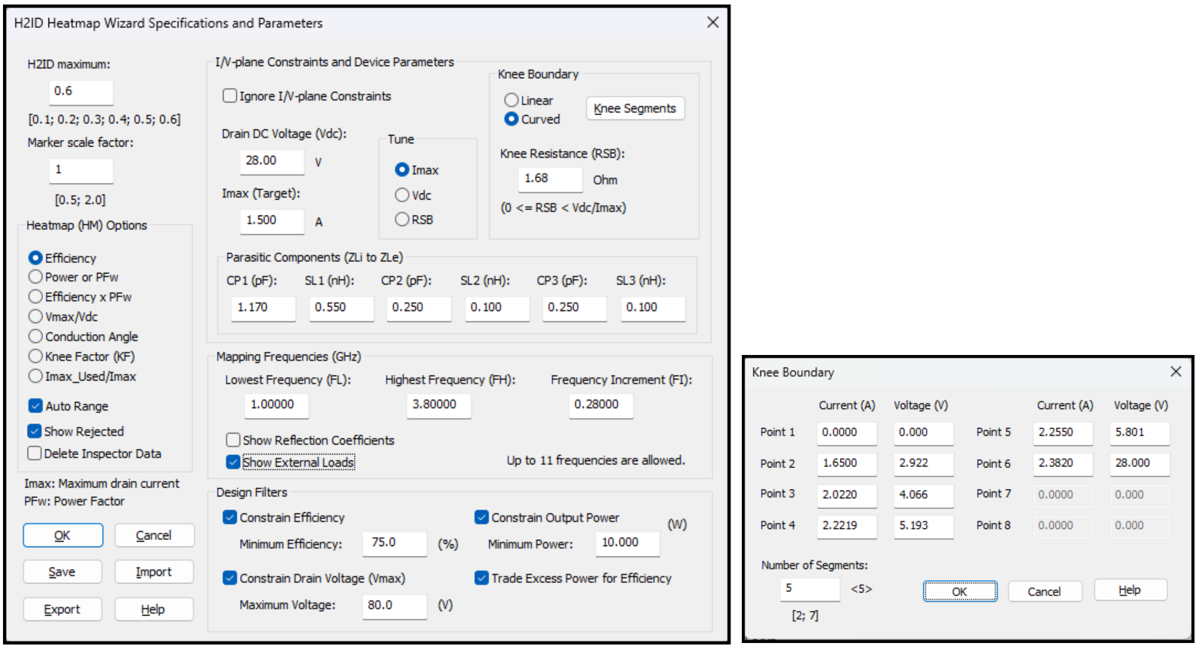

Figure 5. The heatmap and device parameters, the design filters provided and the heatmap options are shown here.

The controls for the wizard are shown in Figure 5. Note that the marker size and the H2ID range can be adjusted. When the Show Rejected heatmap option is selected, hollow markers are used at H2ID operating points not meeting the targets set. When this option is not selected, the relevant markers are not shown.

When the knee boundary is set and the Trade Excess Power option is selected, excess power is traded for out-of-range efficiency by lowering the targeted maximum current (reduced current utilization).

The Save and Import commands are used to save or restore the device specifications and the design filters set.

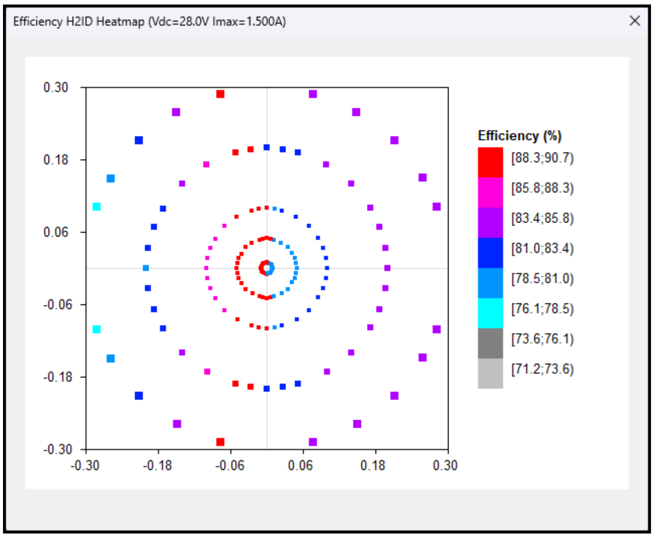

Figure 6. The *H2ID* range was reduced from 0.6 to 0.3 in this example. Note the Class-F-like and Class-B-like efficiency at low distortion levels.

Different frequencies can be assigned to individual inspectors. Left-clicking the empty area just below an inspector heading opens the control shown in Figure 7. The H2ID operating point and assigned frequency can then be changed. The maximum current associated with an inspector can also be frozen, allowing different inspectors to operate at independently selected maximum currents. Subsequent adjustment of the main I_{max} control has no effect on a frozen inspector.

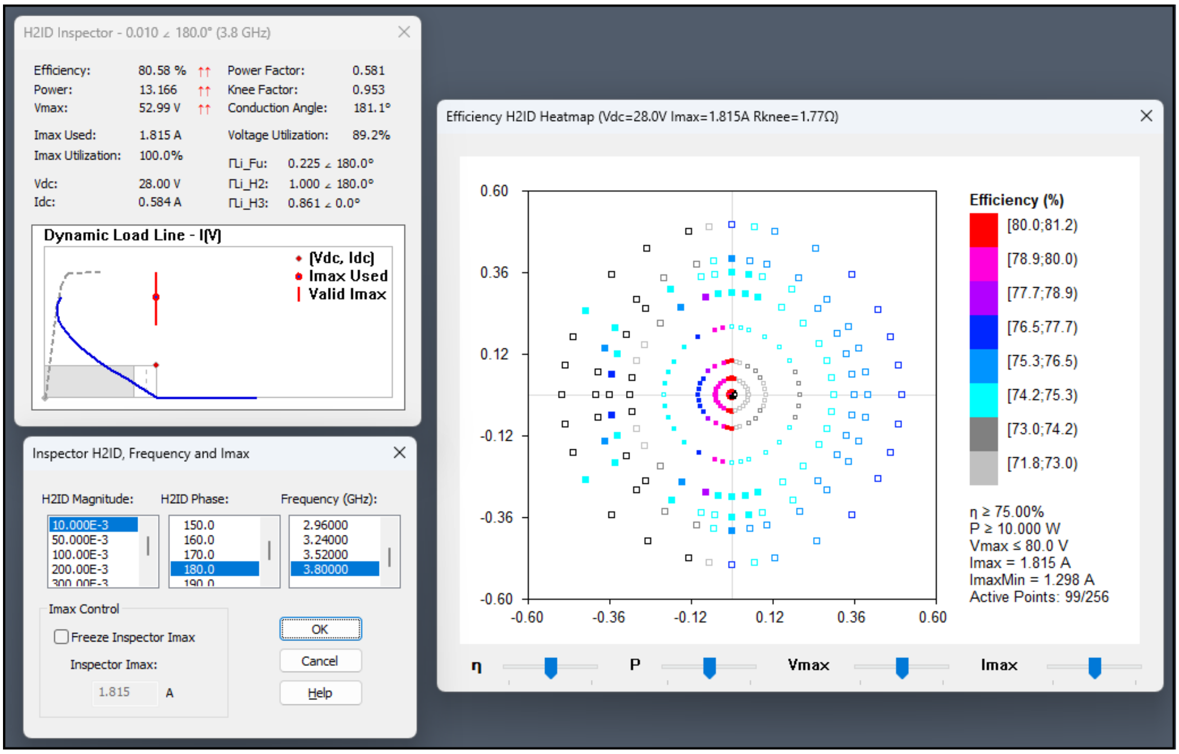

Figure 7. The Inspector H2ID, Frequency and I_{max} control. The H2ID operating point and assigned frequency can be changed, and the maximum current associated with the inspector can be frozen.

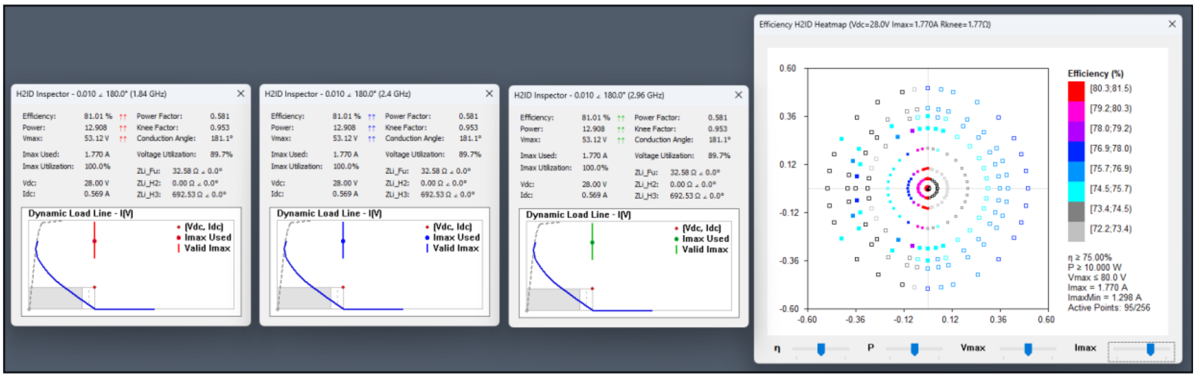

Figure 8. Different frequencies and independently selected operating conditions can be assigned to the inspectors.

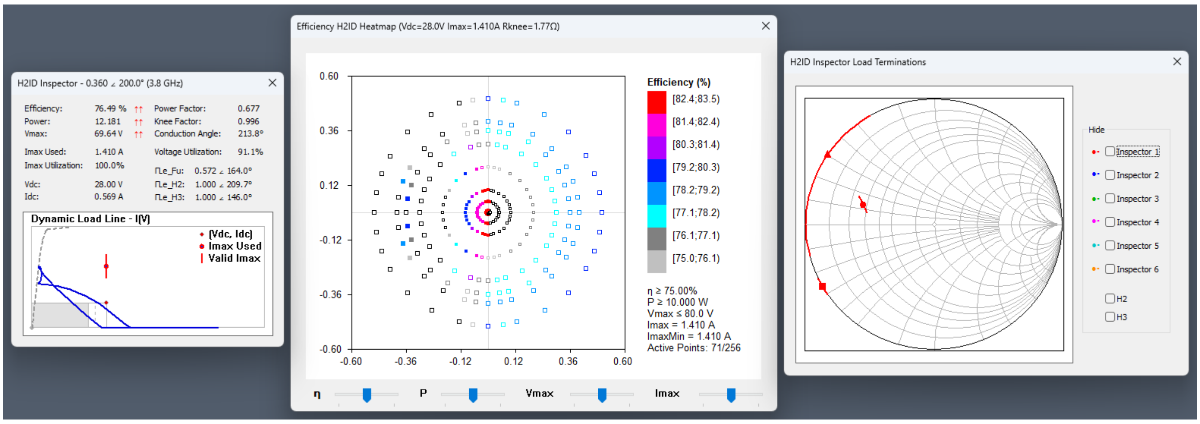

Figure 9. A Smith chart can be opened to display the harmonic terminations associated with the inspectors by double-clicking a point just below the heatmap heading (empty space).

When at least one inspector is open, double-clicking the empty area just below the heatmap heading opens a Smith chart displaying the harmonic terminations associated with the open inspectors (see Figure 9). The terminations associated with points on the valid I_{max} line of each inspector are also shown. These traces are shown in the color assigned to the inspector. Note the options to hide the traces associated with an inspector, or to hide all the second or third harmonic traces.

By assigning different frequencies and operating conditions to the inspectors, the designer can investigate how the required fundamental, second- and third-harmonic reflection coefficients evolve across a frequency band. Candidate operating-point trajectories (mode migration) can therefore be explored before the corresponding harmonic terminations are used as targets for broadband network synthesis (see Figure 10). The maximum currents assigned to the individual inspectors strongly influence the fundamental-frequency terminations, while their effect on the second- and third-harmonic terminations depends on the selected H2ID operating points.

Clockwise rotation of the second- and/or third-harmonic reflection coefficients can reduce the demands placed on the matching network to be synthesized. The second harmonic is particularly important for inverse-Class-F-like operating points, whereas the third harmonic is particularly important for Class-F-like operating points. Anticlockwise rotation of the fundamental-frequency reflection coefficient is generally easier to accommodate, for example through a resonance loop. The Wizard calculates and displays the angular span of the fundamental and harmonic reflection coefficients.

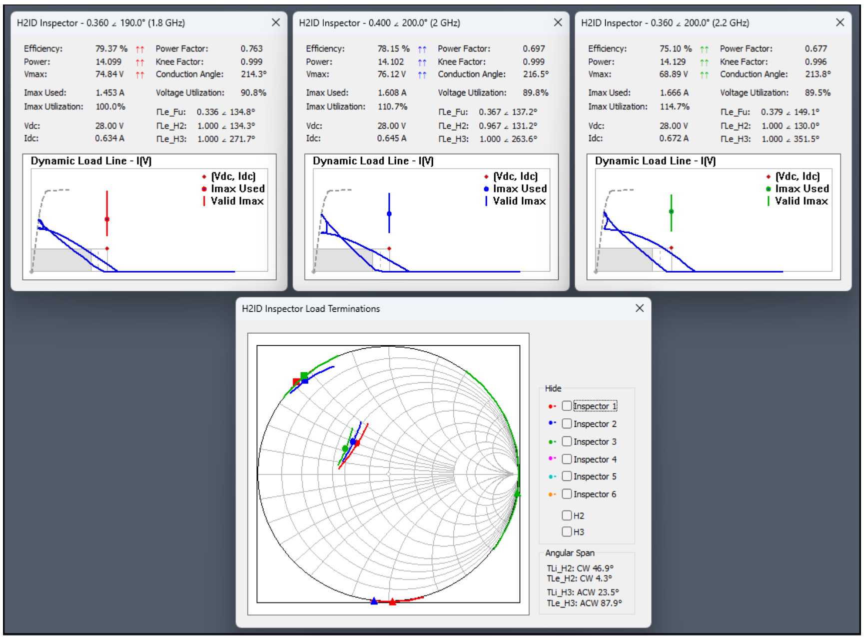

Figure 10. Exploring frequency-dependent harmonic terminations. The maximum current assigned to each inspector can be adjusted to control performance and influence the fundamental-frequency reflection-coefficient trajectory. Different H2ID operating points can be assigned across the band to explore mode migration and reduce undesirable anticlockwise rotation of the harmonic reflection coefficients.

Rather than requiring a single operating mode to be maintained across the entire frequency band, the Wizard allows the designer to explore a controlled path through favourable operating points whose harmonic terminations are collectively more suitable for broadband realization.

The H2ID Heatmap Wizard transforms RF power-amplifier design from a search for a single optimum solution into an interactive exploration of the feasible design space. Designers can identify, inspect and compare practical operating points, explore their behaviour across frequency, and determine the harmonic termination targets required for implementation.

Technical background: The second-harmonic input distortion (H2ID) concepts underlying this design approach are described in Second-Harmonic Input Distortion in Power Amplifier Design, IEEE Microwave Magazine (Early Access), 2026, DOI: 10.1109/MMM.2026.3727968, 15 September 2026.