

Hardware-Driven Mixer Behavioral Modeling with the VanDyke Mixer in SystemVue

What You Measure is What You See – Bench-
Accurate Mixer Modeling

Introduction

Frequency translation sits at the heart of virtually every RF transmitter and receiver, and accurately predicting a mixer's spurious output has always been one of the most difficult problems in system-level simulation. For almost four decades the industry workhorse has been the Intermod Mixer Table (IMT), a format created in 1987 by John Baprawski, an RF engineer and developer of the EEsof OmniSys product. Hewlett Packard acquired EEsof in 1993, Agilent Technologies spun off from HP in late 1999 – the same year the Advanced Design System (ADS) was created – and ADS still uses this mixer model today. The IMT was instrumental in moving the EDA industry forward, but after nearly forty years of use it is time to transition to a model that is easier to characterize, easier to use, and more accurate.

This application note introduces the VanDyke mixer, a new hardware-driven behavioral mixer model in the Spectrasys simulator of Keysight SystemVue. The model was recently granted US patent number 12451985 and ships in the SystemVue 2026 release together with other new WYSIWYG ("What You See Is What You Get") models such as the Variable Gain Amplifier and Measured Intermods. The note walks through the complete flow on real hardware: a Pulsar X2L-10-411 double-balanced mixer is characterized on a Keysight PNA-X network analyzer, the measured peak table is saved in the Keysight Mixer Spur Data MDF format, the Mixer Data Tool converts it into mixer equation data, and Spectrasys reproduces the measured output spectrum peak for peak.

Limitations of the Traditional IMT Mixer

The traditional IMT mixer use model is clunky and carries a long list of limitations that every RF system designer who has characterized a mixer will recognize:

- **Three different file formats.** Formats O, A, and B each address a particular aspect of the model. Format O supports a single RF tone and does not distinguish between sum and difference products; Format A allows sum and difference products to be specified independently; Format B supports two RF input tones. Simply selecting the right format, collecting the data, and reformatting it is tedious and time-consuming.
- **Compression and saturation are hard to capture.** These effects can only be modeled with formats A and B, and only if sufficient data has been collected at multiple input power levels reaching into compression.
- **No third-order intercept entry.** There is no way to specify the IP3 needed to model the in-channel third-order intermod ($2F_1-F_1$), the primary intermod responsible for AM-to-PM distortion.
- **Noise-floor padding.** The rectangular table format forces users to enter values for spurs that fall below the measuring instrument's noise floor, so artificial entries such as ">99" or "NA" end up in the data.
- **Non-intuitive data.** Looking at an index-based table, it is difficult to paint a mental picture of where every intermod lands in the spectrum, and modeling frequency-dependent spurious responses is error-prone.

- **Forward direction only.** IMT tables only support spurious signals flowing forward. This is a serious issue when modeling the conducted emissions from a receiving antenna caused by backward-traveling LO leakage.

In short, the IMT approach demands a large, rectangular grid of index-based measurements, much of which is of no interest to the designer, while making the data that does matter hard to visualize and validate against the bench. The three IMT file formats are documented in the ADS Product Documentation on docs.keysight.com (search for 'IMT Format').

The VanDyke Mixer: A WYSIWYG Modeling Flow

In the early days of computing, text editors improved to the point where the document on screen resembled the final printed page, and the term “What You See Is What You Get” was coined. The VanDyke mixer applies the same idea to mixer characterization: display the mixer output spectrum of interest on a spectrum analyzer, enable the peak table, and the peaks you see are, quite literally, the model. Only the spectrum of interest needs to be measured – signals below the noise floor or of no interest never need to be processed.

Figure 1 summarizes the four-step flow: measure the mixer output on the bench, capture the peak table into an MDF file, convert it with the Mixer Data Tool, and simulate with the VanDyke mixer in SystemVue.



Figure 1. The VanDyke hardware-driven modeling flow – from bench measurement to an RF digital twin in SystemVue.

Keysight Mixer Spur Data Format (MDF)

The measured peak table is saved into a measurement data format (*.mdf) file together with the conditions used to characterize the mixer: the number of input tones and tone spacing, the input frequency and power, and the LO frequency and power. The data block itself is simply a list of measured frequency and power pairs – exactly what the spectrum analyzer peak table reports.

Keysight Mixer Equation Data Format

Mixer equation data is the format consumed directly by the VanDyke mixer. It consists of a header row with units, columns of independent variables (input and LO frequencies and powers), a column of spurious equations, a column of peak powers, and a comment column. The equations combine numeric coefficients and the variables “F1”, “F2”, “FLO”, “IM3F1”, and “IM3F2”; for

example, “-F1+2FLO” specifies a -1 coefficient for the input signal and a +2 coefficient for the LO. “IM3F1” and “IM3F2” are the in-channel third-order intermods that give rise to AM/AM and AM/PM distortion. There is no limit to the number of equations, and unlike a Harmonic Balance circuit simulator, Spectrasys supports multiple colliding tones at the same frequency. The simulator iterates through all equations and uses a multidimensional interpolator to determine the amplitude of the spectrum, so multiple data sets taken across the operating dynamic range can be interpolated between input and LO power levels.

The Mixer Data Tool

The Mixer Data Tool (MDT) in SystemVue converts the raw peak data in the MDF file into an equation block in the mixer equation data format. The MDT builds a master frequency table containing all harmonic combinations of the input and LO frequencies and then iterates through the measured peaks looking for the closest frequency match. If several spurious responses fall at the same frequency, the candidates are sorted using proprietary knowledge of intermod and LO power levels; the most likely equation is used and the alternates are listed in the comment with an “Alt Equ:” tag. Each line’s comment also shows the ideal frequency followed by the measured frequency in parentheses, making it easy to map spectrum peaks to entries in the equation data. Users who already know the equations can bypass the tool and enter them directly.

Reverse-Traveling Leakage and Saturation

Unlike traditional intermod tables, the VanDyke mixer models reverse-traveling signals the same way as forward ones through a dedicated equation data block, typically containing the LO leakage signals traveling backwards. This is critical when modeling conducted emissions coming out of a receive antenna. Spurious growth is also bounded realistically: an IPSat value places a hard limit on total input power, or the highest-power spur set can be designated as the limit so that mixer spurious output can be modeled deep into saturation.

Lab Example: Characterizing a Pulsar X2L-10-411 Mixer

Device Under Test

The device under test is a Pulsar Microwave X2L-10-411, a DC-coupled double-balanced mixer with an 800 to 4000 MHz RF/LO range and SMA connectors. In this lab the mixer is used as a downconverter: the RF input is driven at 1.95 GHz and -15 dBm, the LO at 1.73 GHz and +7 dBm, producing the desired difference-product IF at 220 MHz. The vendor specifications are reproduced in Figure 2.

Specifications

Name	X2L-10-411
Frequency range	LO/RF: 800-4000 MHz IF: DC-700 MHz
LO drive	+7 dBm
Conversion loss	9.0 Db max
1 dB compression point	+1 dBm typ
Isolation	L/R: 25 dB min L/I: 20 dB min
Connector type	SMA
RoHS	RoHS 3 Compliant
ECCN	EAR99
Country of origin	USA



Figure 2. Specifications of the Pulsar X2L-10-411 double-balanced mixer (from the Pulsar Microwave datasheet).

Measurement Setup

A single Keysight PNA-X network analyzer provides the complete bench: two of its internal sources generate the RF and LO stimuli while its Spectrum Analyzer (SA) mode measures the mixer output. Port 1 drives the mixer RF port at 1.95 GHz, -15 dBm; Port 3 drives the LO port at 1.73 GHz, +7 dBm; and the mixer IF output is connected to Port 2, where the SA channel sweeps from 100 MHz to 3 GHz with a 100 Hz resolution and video bandwidth. Figure 3 shows the setup and Figure 4 a close-up of the DUT connections.

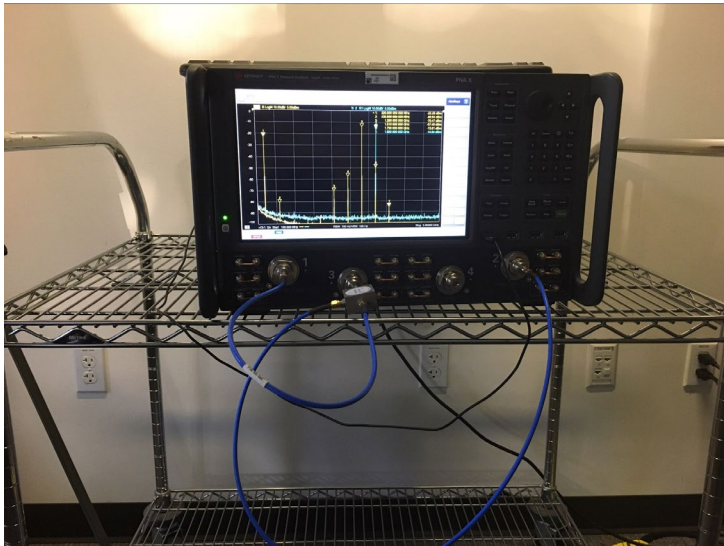


Figure 3. Measurement setup – the Pulsar X2L-10-411 mixer connected to the PNA-X: Port 1 (RF), Port 3 (LO), and Port 2 (IF output to the SA receiver).



Figure 4. Close-up of the DUT. The RF, LO, and IF ports of the X2L-10-411 are clearly labeled on the package.

Before capturing the peak table, the source is calibrated at the DUT plane and a reference trace (R1, shown in blue in Figure 5) records the RF stimulus routed directly to the receiver. The reference marker at 1.95 GHz reads -14.94 dBm, confirming that the intended -15 dBm drive level actually arrives at the mixer RF port – this is the “_cal” reference stored with the measurement.

Measured Output Spectrum

Figure 5 shows the mixer output spectrum (trace B, yellow, with trace max hold enabled) together with the calibration reference trace. Seven markers capture every peak of interest above the noise floor.

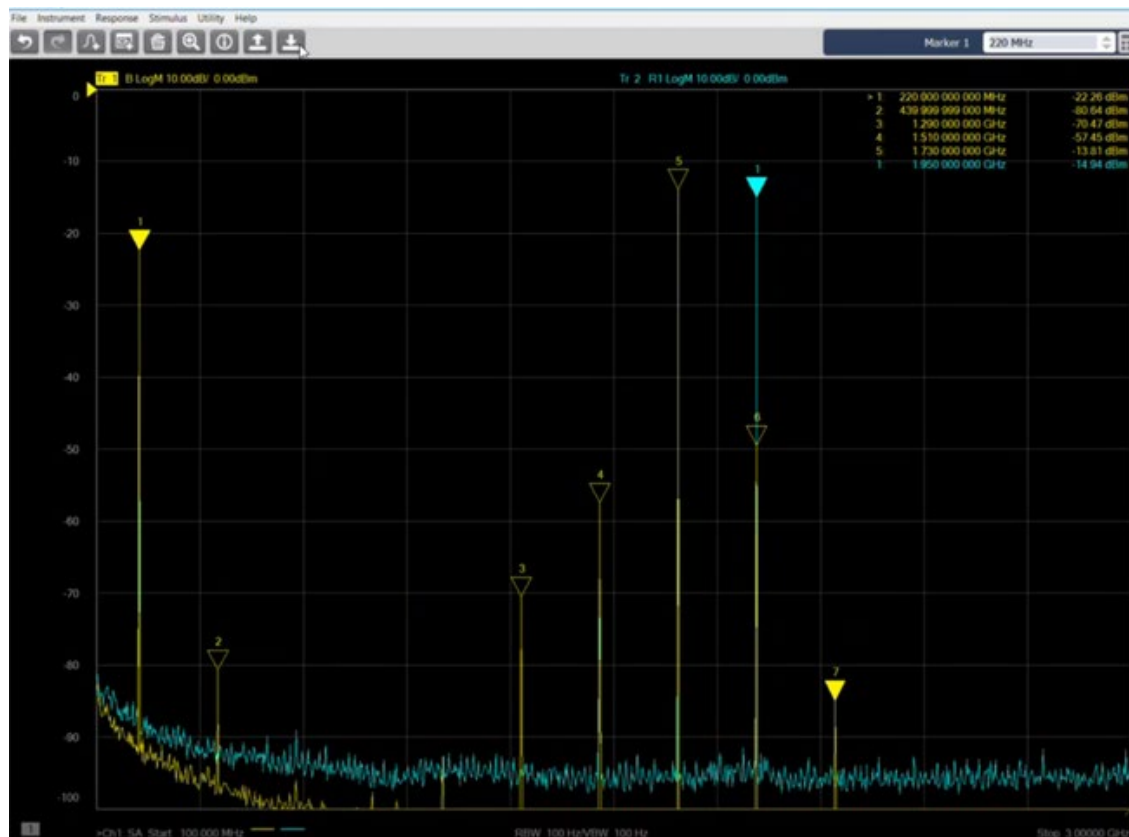


Figure 5. Mixer output spectrum measured on the PNA-X SA channel (yellow) with peak markers, and the RF calibration reference trace (blue).

Table 1 lists the marker data together with the spurious equation each peak corresponds to. With the measured -14.94 dBm RF reference and the -22.26 dBm IF product, the conversion loss is approximately 7.3 dB. The LO leakage at the IF port is -13.81 dBm, corresponding to roughly 20.8 dB of LO-to-IF isolation, and the RF leakage at -49.45 dBm corresponds to about 34.5 dB of RF-to-IF isolation.

Marker	Frequency	Power (dBm)	Equation	Identification
1	220 MHz	-22.26	F1-FLO	Desired IF (difference product)
2	440 MHz	-80.64	2F1-2FLO	Second harmonic of the IF product
3	1.29 GHz	-70.47	3FLO-2F1	Higher-order spur
4	1.51 GHz	-57.45	2FLO-F1	Higher-order spur
5	1.73 GHz	-13.81	FLO	LO-to-IF leakage
6	1.95 GHz	-49.45	F1	RF-to-IF leakage
7	2.17 GHz	-84.87	2F1-FLO	Higher-order spur
Ref	1.95 GHz	-14.94	F1 (reference)	RF stimulus on the calibration trace

Table 1. Measured peak table with spurious identification (RF = 1.95 GHz at -15 dBm, LO = 1.73 GHz at +7 dBm).

Notice how little data collection was required: only the eight peaks visible on the analyzer were recorded. There is no rectangular grid to fill in, no index bookkeeping, and no artificial entries for spurs buried in the noise floor.

Creating the MDF File

The marker table is exported from the instrument and pasted into the Keysight Mixer Spur Data template, producing the file MixerRF1p95GLO1p73G_cal.mdf shown below. The header records the measurement conditions; the Peak block holds the frequency and power pairs exactly as measured.

```
! Keysight Spur Data Format
! Converted from Peak Table
! NumTones = 1, ToneSpacing = 220 MHz
! InPower = -15 dBm, InFreq = 1.95 GHz
! LOPower = +7 dBm, LOFreq = 1.73 GHz
!
! Units: Freq(Hz) Power(dBm) ToneSpacing(Hz)
! Save as '.mdf' file and import into Tools > Applications > Mixer Data Tool...

SCALAR
NumTones(int) 1
ToneSpacing(real) 220e6 Hz
END

VAR InPower(real) = -15
VAR InFreq(real) = 1.95e9
VAR LOPower(real) = 7
VAR LOFreq(real) = 1.73e9

BEGIN Peak
% Freq(real) Power(real)
220000000.000 -22.26
439999999.000 -80.64
129000000.000 -70.47
151000000.000 -57.45
173000000.000 -13.81
195000000.000 -49.45
217000000.000 -84.87
195000000.000 -14.94
END
```

Building and Validating the Model in SystemVue

Importing with the Mixer Data Tool

Open the workspace "Vandyke Mixer S1000 Lab initial.wsv" and launch the Mixer Data Tool from Tools > Applications > Mixer Data Tool, as shown in Figure 6. This starting workspace is available for download from the Keysight Knowledge Center:

<https://docs.keysight.com/download/attachments/1037048395/Vandyke%20Mixer%20S1000%20Lab%20initial.wsv?api=v2>

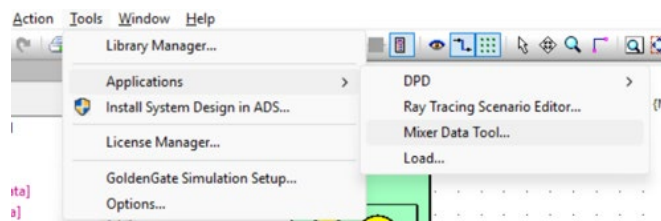


Figure 6. Launching the Mixer Data Tool from the SystemVue Tools > Applications menu.

Browse to the MDF file. The tool displays the file contents on the left and immediately generates the corresponding mixer equation data on the right (Figure 7). Every measured peak has been mapped to its spurious equation, with the ideal and measured frequencies shown in the comment of each line. Click “To Clipboard” and paste the block into an Equations item in the workspace.

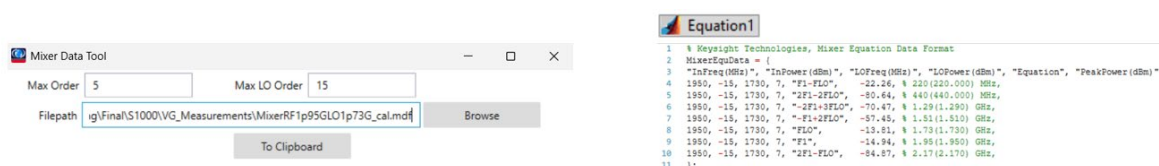


Figure 7. Mixer Data Tool: the imported MDF peak data (left) and the automatically generated Keysight Mixer Equation Data (right).

Inspecting the Equation Block

Figure 8 shows the resulting Multi Independent Parameter (MIP) equation in the SystemVue equation editor. Each row carries the independent variables (1950 MHz at -15 dBm input, 1730 MHz at +7 dBm LO), the spurious equation, and the measured peak power. Before simulating, verify that the source and LO frequencies and power levels used in the design match the measurement settings – the model is anchored to the conditions under which the data was taken.

```

1 % Keysight Technologies, Mixer Equation Data Format
2 MixerEquData = {
3   "InFreq(MHz)", "InPower(dBm)", "LOFreq(MHz)", "LOPower(dBm)", "Equation", "PeakPower(dBm)"
4   1950, -15, 1730, 7, "F1-FLO", -22.26, % 220(220.000) MHz,
5   1950, -15, 1730, 7, "2F1-2FLO", -80.64, % 440(440.000) MHz,
6   1950, -15, 1730, 7, "~2F1+3FLO", -70.47, % 1.29(1.290) GHz,
7   1950, -15, 1730, 7, "~F1+2FLO", -57.45, % 1.51(1.510) GHz,
8   1950, -15, 1730, 7, "FLO", -13.81, % 1.73(1.730) GHz,
9   1950, -15, 1730, 7, "F1", -14.94, % 1.95(1.950) GHz,
10  1950, -15, 1730, 7, "2F1-FLO", -84.87, % 2.17(2.170) GHz,
11 };
```

Figure 8. The mixer equation data pasted into an Equations item in the SystemVue workspace.

Simulation and Validation

The Spectrasys schematic in Figure 9 could hardly be simpler: a source drives the VanDyke mixer input, a second source drives the LO port, and the output feeds a port where the spectrum is evaluated. The mixer consumes the equation data variable directly.

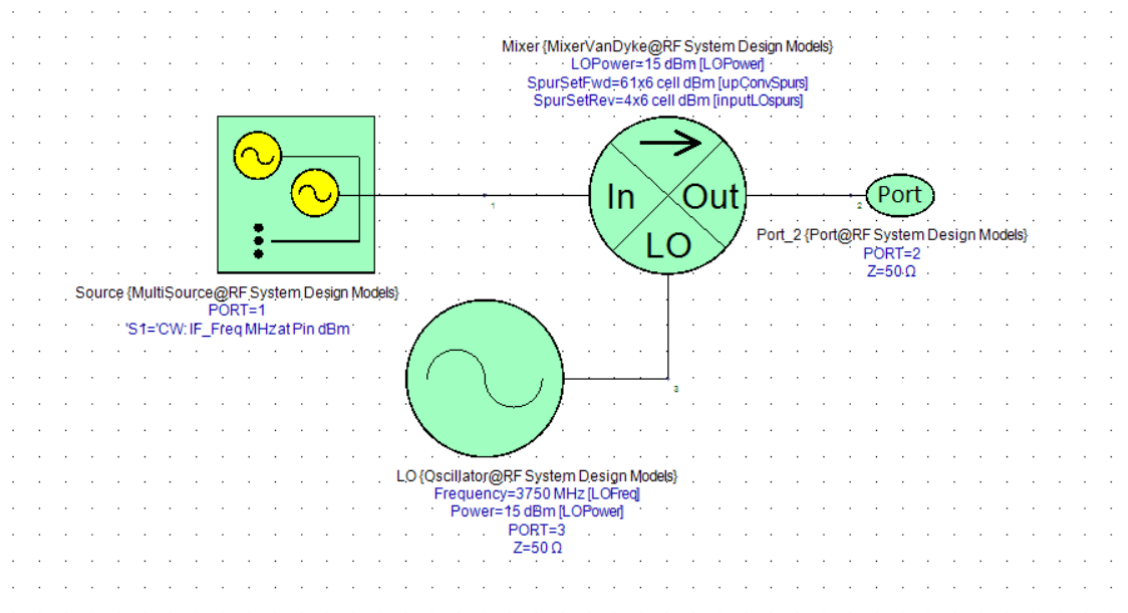


Figure 9. Spectrasys schematic of the VanDyke mixer test bench in SystemVue.

Running the simulation produces the output spectrum in Figure 10. Every measured peak appears at its measured frequency and amplitude – the desired 220 MHz IF, the LO and RF leakage, and each higher-order spur. Comparing Figure 10 with the measured spectrum in Figure 5 demonstrates the WYSIWYG promise: what was measured on the bench is exactly what the simulator reproduces. A LiveReport can then be created to document the result alongside the schematic and equations.

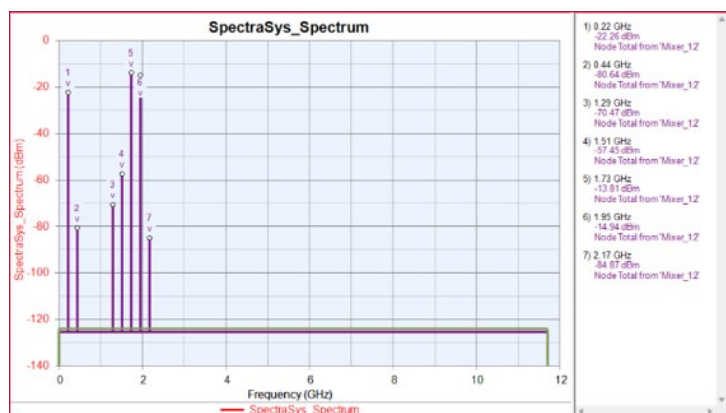


Figure 10. Simulated VanDyke mixer output spectrum in Spectrasys, reproducing the measured peak table.

Figure 11 shows the LiveReport generated for this lab, placing the simulated Spectrasys spectrum and the measured spectrum with its peak table side by side – they match.

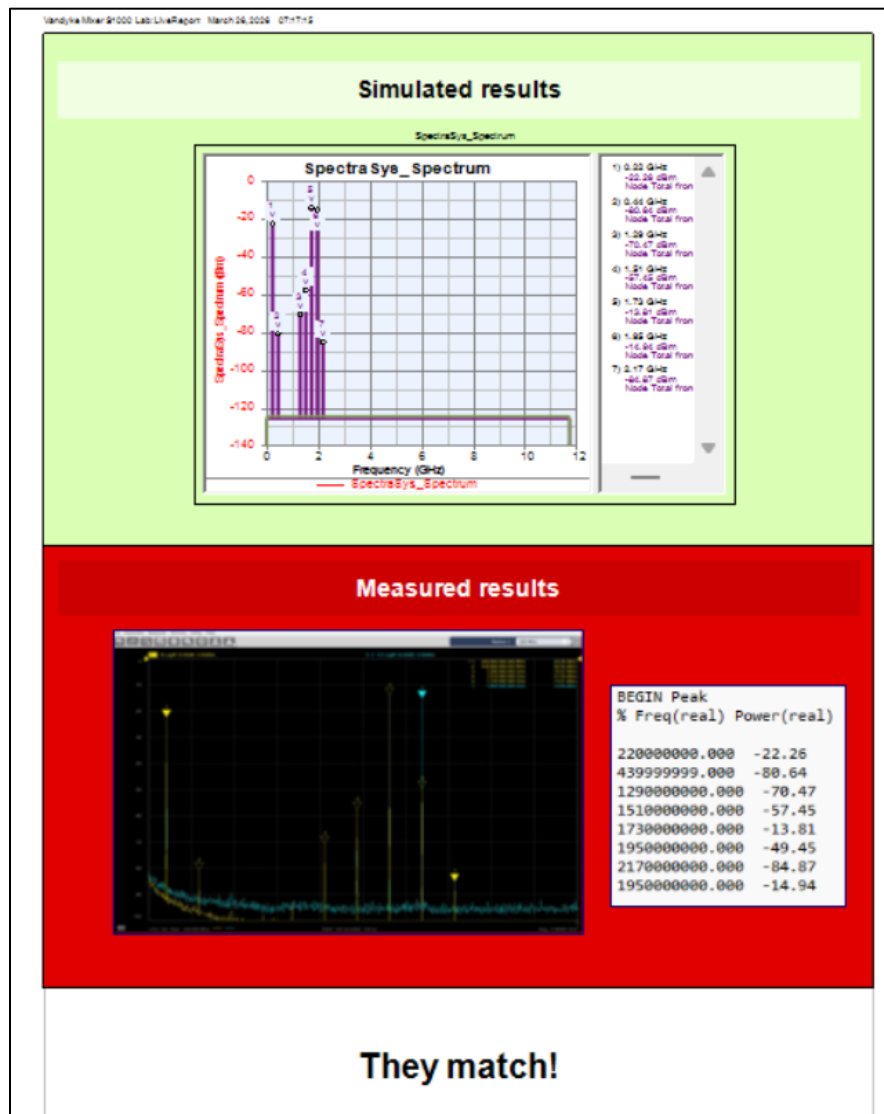


Figure 11. LiveReport comparing the simulated and measured mixer output spectra – the results match peak for peak.

The completed workspace “Vandyke Mixer S1000 Lab.wsv”, with the imported equation data and simulation results, is available for download from the Keysight Knowledge Center:

<https://docs.keysight.com/download/attachments/1037048395/Vandyke%20Mixer%20S1000%20Lab.wsv?api=v2>

A video of the measurement is also available in the Keysight Knowledge Center:

<https://docs.keysight.com/download/attachments/1037048395/Mixer%20Measurement%202026.mp4?api=v2>

Key Advantages of the VanDyke Mixer

- **Hardware-accurate WYSIWYG modeling.**

The model is built directly from measured spectrum peak tables, so the simulated spurs, leakage, and non-linear behavior match what is seen on the bench – all the way into saturation.

- **Radically simpler characterization.**

One file format replaces the three IMT tables. Only the peaks of interest are measured – no rectangular grids, index bookkeeping, or noise-floor padding – and the Mixer Data Tool generates the spurious equations automatically.

- **Complete spurious physics, forward and reverse.**

One- and two-tone equations with in-channel third-order distortion, power and frequency dependency through interpolation, and reverse-traveling LO leakage for conducted-emissions analysis.

Conclusion

This lab demonstrates the complete hardware-driven modeling flow for the VanDyke mixer: measure the output spectrum peak table of a real mixer on a PNA-X, save it in the Keysight Mixer Spur Data MDF format, convert it with the Mixer Data Tool, and simulate in Spectrasys. In a matter of minutes the bench measurement becomes a behavioral model whose simulated spectrum matches the measured one peak for peak, including real spurs and real leakage. By replacing four decades of index-based intermod tables with an intuitive, measurement-native equation format, the VanDyke mixer – granted US patent 12451985 and shipping in the SystemVue 2026 release – delivers a true RF digital twin of the mixer and makes it dramatically easier to build.

For More Information

To learn more about SystemVue system simulation, check the following link:

<https://www.keysight.com/find/systemvue>

For SystemVue documentation, including the VanDyke mixer and the Mixer Data Tool, visit: <https://docs.keysight.com/display/support/SystemVue+Support+Home>

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