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Non-Linear Simulation of RFIC Amplifier Reference Design Boards

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This article describes the subsystem-level simulation of reference designs for use as "component" within a larger overall design

Today there is a trend away from brute-force bench tuning and towards increased use of circuit simulation as the path for rapid prototype success of microwave designs at the circuit as well as sub-system levels. There are many choices for designers, including the option of choosing a nearly ready-to-use packaged RFIC amplifier in lieu of designing their own amplifier from scratch. Often, application information related to such packaged RFICs includes a complete reference design that is supplied and/or can be fabricated on a PCB board that includes external matching and bias components and a transmission line interconnect layout. Packaged RFIC amplifiers can be readily cascaded on a board (or within a multi-chip module of some form) with filters, mixers, switches and other system level components to comprise complete RF sub-system front-ends.

What is not widely available yet, however, are useful models for such system level components. A good starting point towards such model availability would be *S*-parameters that have clearly defined reference planes at the edge of the components. Some companies do provide such data, but not all are taking such data in a form that is directly usable by the designer for even accurate linear predictions of cascaded component performance, due mainly to reference planes not located at the package pins of the components. One workaround in this case is to perform or obtain customized *S*-parameter measurements of the packaged RFIC amplifier and use other available models for the remainder of the reference design's transmission line and surface mount components. Such an approach was described by our group in a paper that described linear simulations that enabled design frequency and board type translation as well as stabilization for a packaged LNA reference design [1].

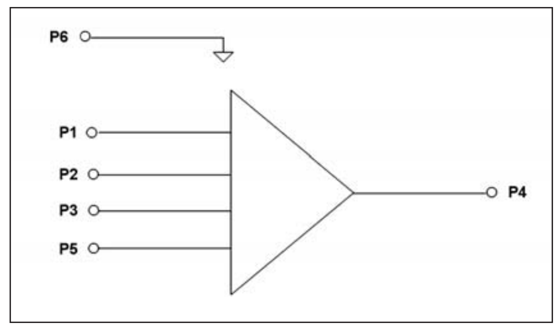


Figure 1 · NEC UPC8179TK-E2-A amplifier model topology. Pins P2, P3, and P5 are not used in this particular part's model.

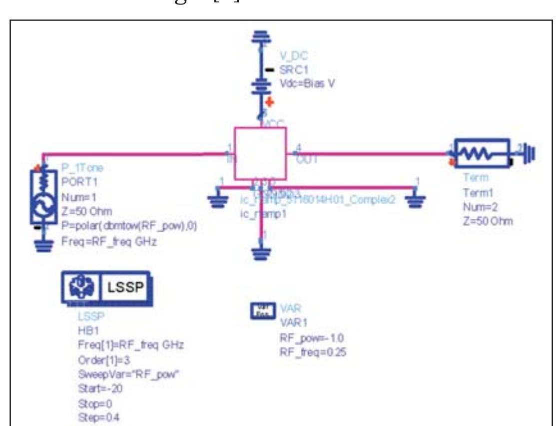


Figure 2 · ADS Test Bench for large signal *S*-parameters using the P2D Data file format.

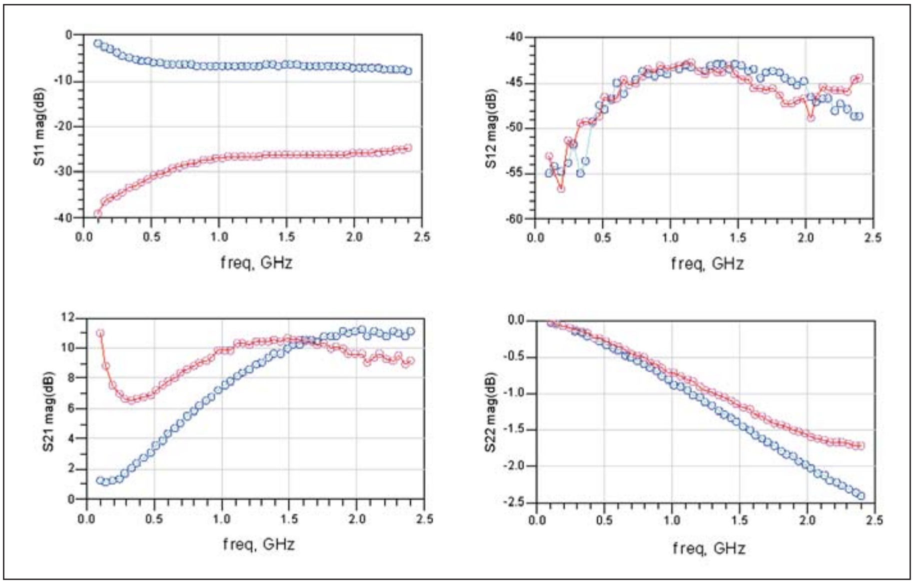


Figure 3 · Simulated small-signal *S*-parameter data on 4 mil Rogers 4350 and 16 mil Rogers 4003 compared to the model at 3.3V, –40°C. Blue circles are measurements on 4 mil Rogers 4350 substrate; light blue line is model performance for 4 mil Rogers 4350; pink circles are measurements on 16 mil Rogers 4003; red line is model performance for 16 mil Rogers 4003.

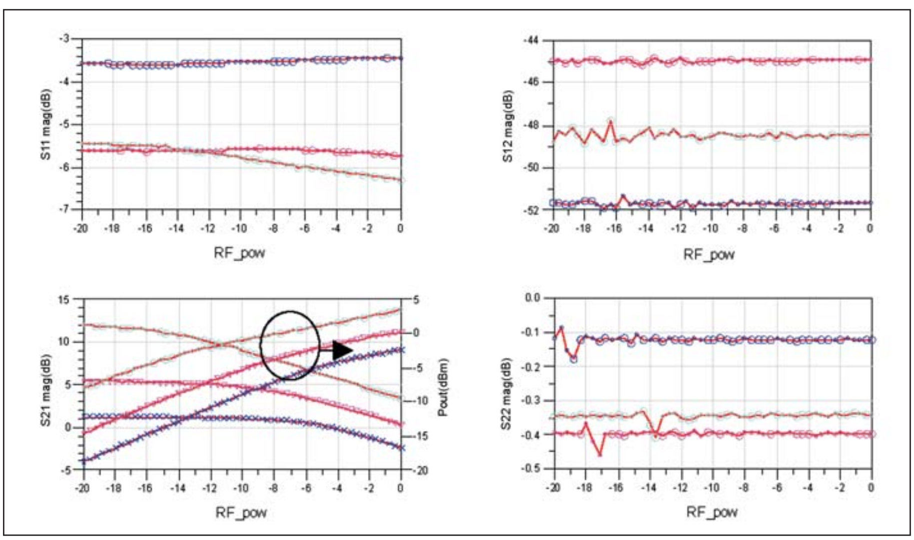


Figure 4 · Swept power *S*-parameter data on 4 mil Rogers 4350 for the 5116014H01 at 2.4V and 25°C, at 0.25 GHz, 0.75 GHz and 2.4 GHz. Red Line is model performance at 0.25 GHz, 0.75 GHz and 2.4 GHz; blue circles are measured data at 250 MHz; pink circles are measured data at 750 MHz, light blue circles are measured data at 2.4 GHz.

Increasingly, designers need to perform non-linear simulations of their circuit designs. While behavioral modeling of amplifiers is a very active research area with many ongoing developments, a practical approach that enables non-linear simulations of amplifiers is the use of the P2D amplifier model included within the Agilent Advanced Design System (ADS) circuit simulator [2, 3]. The present treatment exemplifies a recommended modeling approach consisting of a P2D non-linear behavioral model for a NEC UPC8179TK surface mount packaged amplifier combined with accurate and highly scalable parasitic models [4] for external passive elements and careful modeling of all transmission line and via effects.

Development and Validation of a P2D-Based Behavioral Model

The model developed for the NEC UPC8179TK predicts the *S*-parameter performance of the packaged IC as a function of frequency, bias voltage, substrate parameters, power and temperature. Measurements used to build the model were based on fixtures fabricated on 4 mil Rogers 4350 and 16 mil Rogers 4003 substrates. *S*-parameter measurements were taken from 0.1~2.4 GHz, at –40°C and 25°C and 80°C, at 2.4V and 3.3V bias. The reference planes for the measurements were at the outer edges of the pad-stack. Swept power *S*-parameters were performed at 250 MHz, 500 MHz, 750 MHz, 1 GHz and 2.4 GHz at 25°C and 80°C at 2.4V and 3.3V bias. The model is valid from –20 dBm to –1 dBm RF input power for 16 mil substrate and assumes that the DC path is isolated from the RF path.

Figures 1 and 2 illustrate the model topology and schematic setup information, and example simulation results for the amplifier model are compared to measurements in figures 3 and 4. Figure 3 shows that the data-driven model recreates measured small-signal *S*-parameters exactly for the two substrates used to build the model (the data symbols are right on top of the simulation lines). In between measured conditions the model performs a multi-dimensional interpolation so that performance using other bias conditions, temperatures, substrate conditions, etc. can be predicted reliably. It is not recommended that the model be used for extrapolations outside of the mea-

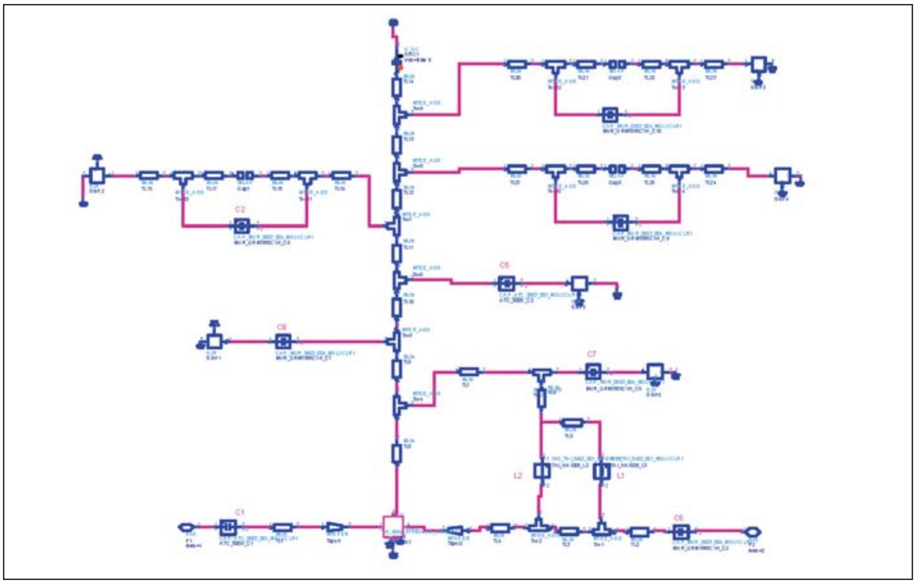


Figure 5 · Validation circuit design as represented in ADS 2006 using transmission line elements and Modelithics CLR components at 2.4 GHz.

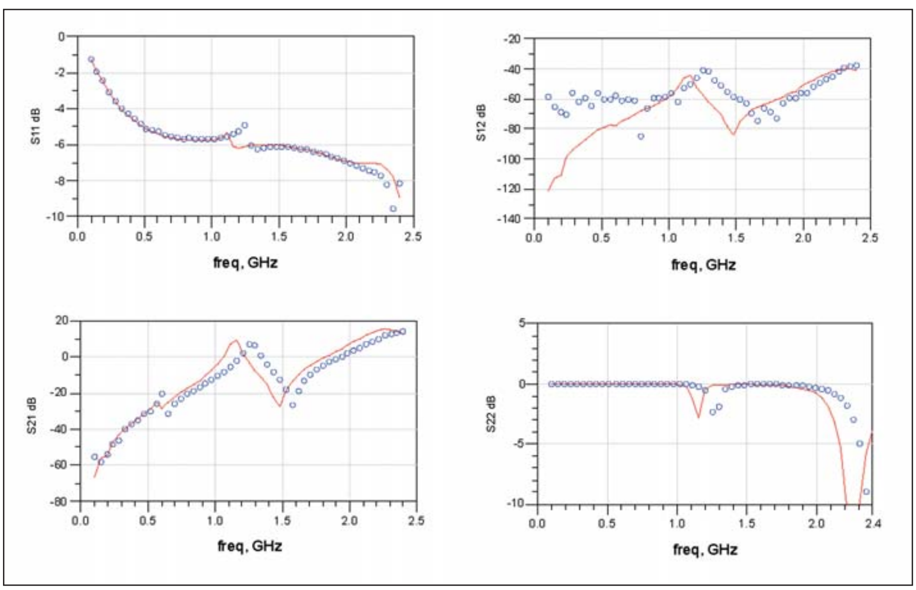


Figure 7 · *S*-parameter data for the validation circuit for NEC UPC8179 amplifier on 16 mil Rogers 4003 compared with the model at 2.4V Vcc, 25°C. Red line is model performance; blue circles are measurements using 16 mil Rogers 4003 substrate.

L1	2.7nH	Taiyo Yuden	HK10052N7S-T
L2	3.9nH	Taiyo Yuden	HK10053N9S-T
C1, C5	51pF	ATC	600S510FTK01Q510BFS
C2, C3, C4, C8	1000pF	Murata	GRM1885C1H102JA01
C6	0.5pF	Murata	GRM1885C1HR50CZ01
C7	5.6pF	Murata	GRM1885C1H5R6DZ01

Table 1 · Models used for reference validation design.

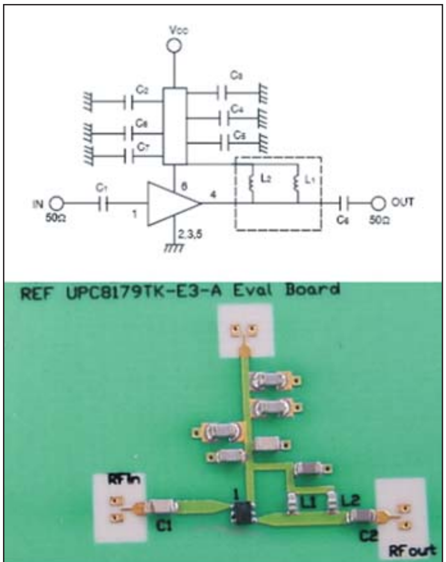
sured conditions used to build the model, however. Figure 4 shows the power dependent *S*-parameter performance at various frequencies. Most interesting is S_{11} and S_{21} behavior with input drive level. Although not specifically shown, AM/PM (S_{21} phase) information is also predicted with this approach.

Simulation and Validation of a Complete Reference Design

A 2.4 GHz validation circuit was developed and fabricated on a 16 mil Rogers 4003 substrate. The design used as a starting point a reference design suggested by the manufacturer's data sheet for this part [4]. Modelithics CLR library has been used for the passive component selection and representation for the design. Figures 5 through 11 show the simulation setup, reference board topology and results for simulation and measured results achieved for this design.

Summary

The recommended design approach, enabled by the behavioral model of the packaged amplifier, produced excellent simulation to measured comparisons of the example 2.4 GHz amplifier circuit for both linear and power swept behavior. Statistical analyses were included to demonstrate just some of the flexibility and power of the combined set of models used to assemble the reference design simulation model. Statistical analysis results are well matched with sweep frequency data and sweep power data. The vendor quoted tolerance for these parts is as large as 10%. The real power of this simulation approach is that designers that are equipped with a complete and accurate simulation model for a reference design like that shown herein, can proceed to retune the design for a better match their specific requirements (substrate, frequency range, bias, etc.), and they can quickly evaluate whether the component will



COMPONENT LIST

FORM	SYMBOL	VALUE
Chip Capacitor	C7	5.6 pF
	C6	0.5 pF
	C1, C5	51 pF
	C2, C3, C4, C8	1000 pF
Chip Inductor	L2	3.9 nH
	L1	2.7 nH

Figure 6 · The NEC UPC8179 2.4 GHz reference validation circuit design used in this work. The circuit was fabricated on a 16 mil Rogers 4003 board. Also shown is the manufacturers recommended component list.

actually meet their requirements, which more often than not will be different than the typical manufacturers reference design setup.

References

1. J. Capwell, B. Clausen, T. Weller, and L. Dunleavy, "Accurate Models Simplify Reference Designs for RFIC Amplifiers," *High Frequency Electronics*, November 2005.

2. Advanced Design System software documentation, Agilent Technologies Inc., Palo Alto, CA.

3. L. Dunleavy and J. Liu, "Understanding P2D Nonlinear Models," *Microwaves & RF*, July 2007.

4. "Comprehensive Models for RLC Components to Accelerate PCB Designs," Product Note, *Microwave Journal*, May 2004.

5. Data sheet for UPC8179TK amplifier, available at http://www.cel.com/pdf/datasheets/upc8179tk.pdf

Acknowledgements:

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Please contact Modelithics at info@modelithics.com to request a free download of this example circuit.

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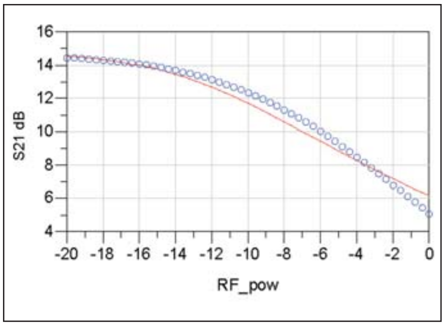

Figure 8 · Swept power gain (dB) for reference validation circuit (2.4 GHz) for NEC UPC8179 amplifier on 16 mil Rogers 4003 compared with the model at 2.4V Vcc, 25°C. Red line is model performance; blue circles are measurements.

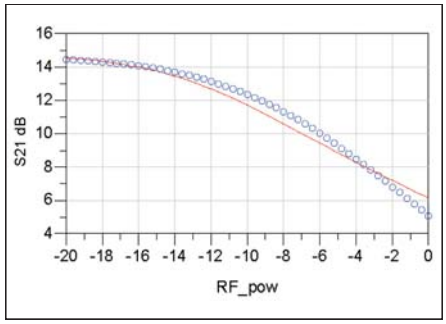

Figure 9 · Swept power gain (dB) for reference validation circuit compared with the model at 2.4V Vcc, 25°C and 2.4 GHz. Red line is model performance; blue circles are measurements on 16 mil Rogers 4003 substrate.

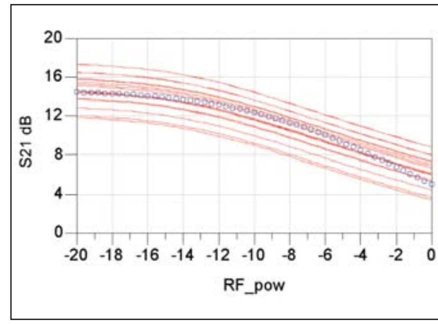

Figure 11 · Swept power gain measurement (dB) for the validation circuit compared with the model at 3.3V Vcc, 25°C and 2.4 GHz. Statistical analysis was performed on the inductors and capacitor to verify tolerance (10%) effects.

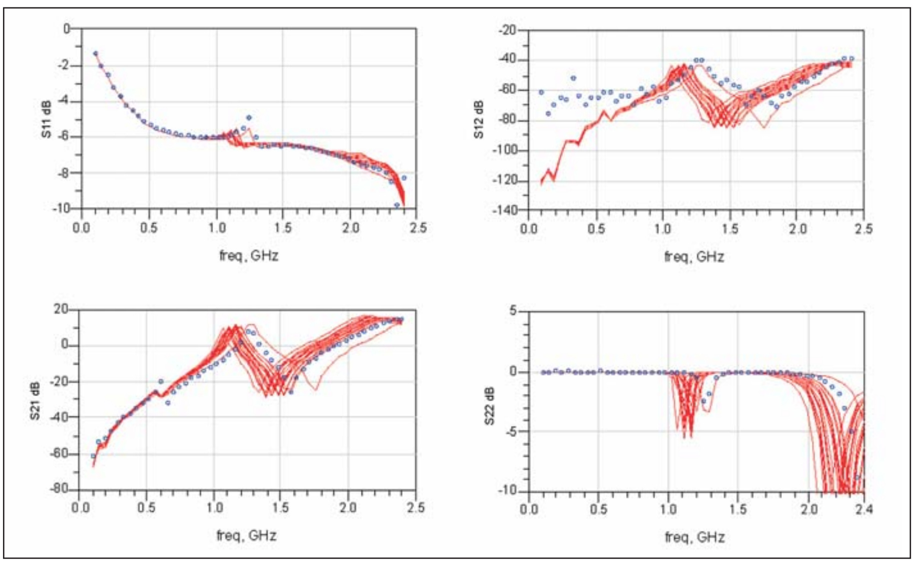

Figure 10 · *S*-parameter data for reference validation circuit compared with the model at 3.3V Vcc, 25°C. Statistical analysis has been performed on the Taiyo Yuden inductors (2.7 nH and 3.9 nH) and Murata capacitor (5.6 pF) to analyze tolerance (10%) effects.

Author Information

Hetvi Patel received the B.E. degree in electronics and communication from South Gujarat University, India, in 2001 and Master of E-Business from Sardar Patel University, India, in 2004. She received an MSEE from University of South Florida in 2006 and joined Modelithics in the same year. She is currently an RF engineer at Modelithics Inc., working on measurements and modeling projects for active and passive devices.

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