From November 2005 *High Frequency Electronics*

Accurate Models Simplify Reference Designs for RFIC Amplifiers

By John Capwell, Bill Clausen, Tom Weller and Larry Dunleavy
Modelithics, Inc.

This article shows how a manufacturer's amplifier reference design can be adapted for use at different frequencies, using different substrate materials

As the wireless communications market has grown, reference designs for packaged RFIC devices have become very popular. With a proven board layout and component selection, engineers can incorporate a particular RFIC into a new product faster and easier, with the knowledge that the device will operate as specified.

However, reference designs can have some significant limitations. The intended application may operate at a frequency and PCB board environment that is different from that which the reference design was characterized. Also, the engineer may wish to use passive components from suppliers other than those chosen by the RFIC manufacturer for the reference design. Finally, appropriate models for simulation of the RFIC and its selected supporting components may not be included as part of the reference design package.

This article explains how an accurate and scalable passive component model library enables reliable simulation of the reference design, allowing it to be adapted for a particular application. We will describe the CLR Model Library from Modelithics, Inc. and show how it can be used along with measured RFIC amplifier data, with the part mounted on the chosen board, to achieve a successful adaptation from the reference design to the designer's preferred topology and component selection.

The CLR Model Library

Modelithics has developed a unique library of models for surface mount passive components (inductors, capacitors, resistors) from more than a dozen different vendors. There are 60 Global Models™ covering body sizes from 0201 to 1210. Global Models represent entire part value ranges with a single model and have features such as part value scaling, substrate scaling, high-order resonance effects and accurate effective series resistance (ESR) values (Figure 1). Each model is thoroughly documented with a conveniently accessible model information data sheet

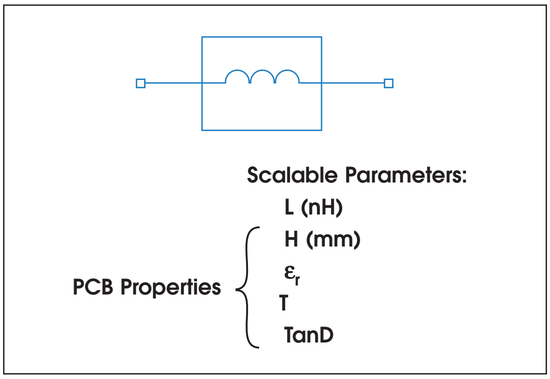

Figure 1 · Global Models include scalable part value and substrate properties, as illustrated here for an inductor.

Design Example

Figure 2 shows a manufacturer's evaluation board for a packaged RFIC amplifier. This layout and selection of components comprises a reference design intended for use at 1.9 GHz. S-parameter data is available, but only for the ports at the edge of the complete reference board. The evaluation board uses 31 mil FR4 with grounded coplanar waveguide interconnecting transmission lines and SMT

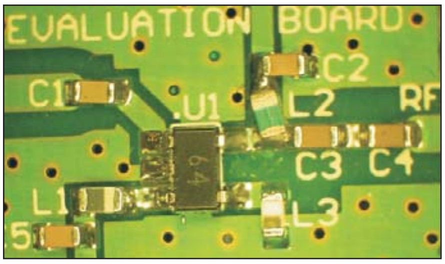

Figure 2 · Manufacturer's evaluation board for an RFIC amplifier, designed for 1.9 GHz operation.

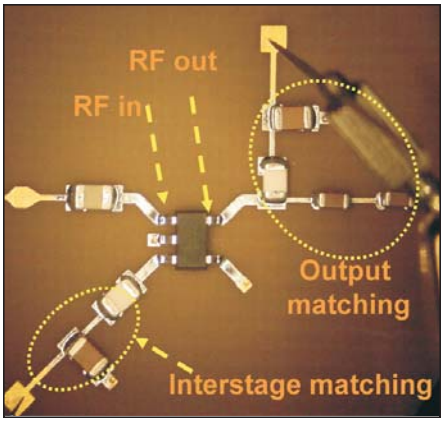

Figure 3 · Desired layout for the RFIC amplifier circuit, which will operate at 2.3 GHz.

lumped element components for coupling and matching. The manufacturer specifies an operating band of 1.93 to 1.99 GHz with 18 dB of gain.

The desired application is for a center frequency of 2.3 GHz with construction on FR4 using microstrip interconnections and SMT components. Design goals include good gain and match at the new frequency. The desired board layout is shown in Figure 3.

The plots in Figure 4 show three sets of measured data—from the original evaluation board; the same design translated to microstrip on 21 mil FR4 using the same passive components; and the translated design with components of the same nominal values, but from other vendors. The plots clearly show the effects of the layout change on matching and gain. Note the significant frequency shift when different vendors' components are substituted for the original parts. The translated design also introduces a region of instability below about 1.4 GHz.

The evaluation board data was taken from the vendor's website. The measurement on the all the FR4 substrates was performed using an "on-board" TRL calibration along with RF probes from GGB Industries. The calibration set the reference plane at the input and output of the matching networks. It is surmised that the instability of the FR4 mounted amplifier at low frequencies, evident from the S_{11} data, is caused from the increased (via) inductance associated with the backside microstrip ground versus the topside ground afforded by the original reference design.

Following the translation to a microstrip layout, the next step was to shift the center frequency to 2.3 GHz. To do this, the circuit was modeled by first measuring the S-parameters of the amplifier (with bias networks included) on a 14 mil FR4 board and incorporating the CLR Library passive component models in the simulation. As shown in the plots of Figure 5, good matching and gain was obtained, but the instability problem (S_{11} > 0 dB) at lower frequency, while now fully predicted, remains a problem.

The simulation was repeated using 5 mil FR4 (Figure 6). Again, the measurements confirm the accuracy of the models, in this case, the scalability of substrate parameters. This modeling approach was thus validated by fabricating and measuring circuits on multiple boards. It should be noted that the external matching element values needed to realize the 2.3 GHz matching goals changed between the 5 mil and 14 mil implementations.

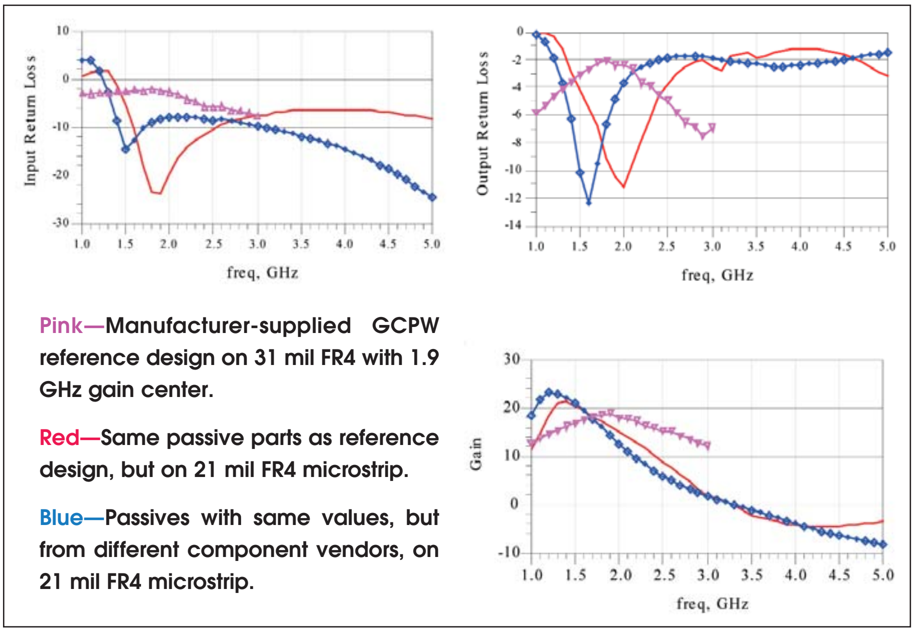

Figure 4 · Simple translation from the manufacturer's reference design to a FR4 microstrip design introduces frequency shift and instability.

Stabilizing the Circuit

With measurements confirming the ability of the models to accurately predict circuit operation, the issue of stability can be addressed. To improve circuit stability at the lower frequencies, changes were made to the input matching and to the DC bias portions of the circuit (Figure 7).

Stability was achieved by the addition of a loaded shunt stub on the output in conjunction with changing the topology of the DC (V_{cc}) feed to include an additional shunt capacitor and a series resistor. The input was

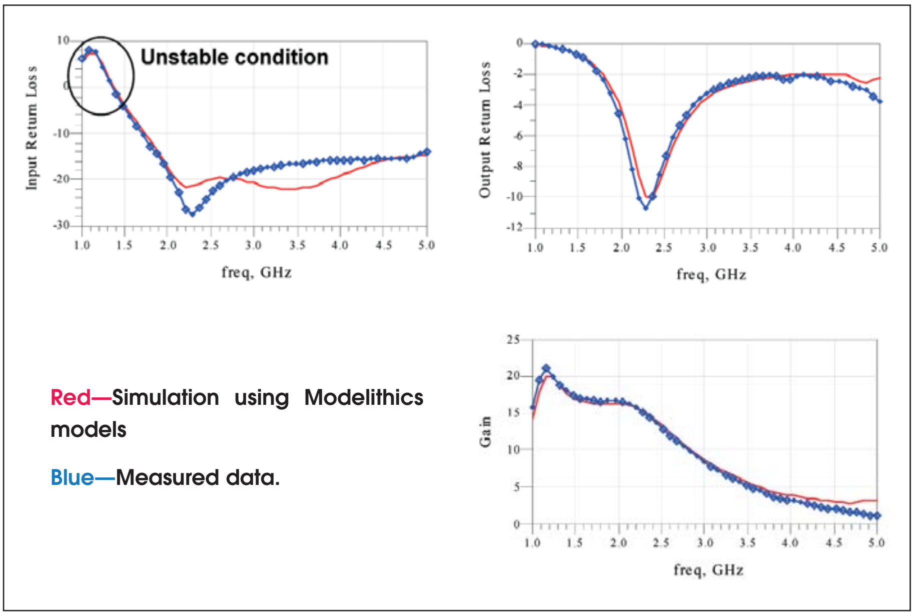

Figure 5 · 14 mil FR4 LNA circuit results showing the desired frequency change, but instability is predicted and measured below 1.4 GHz.

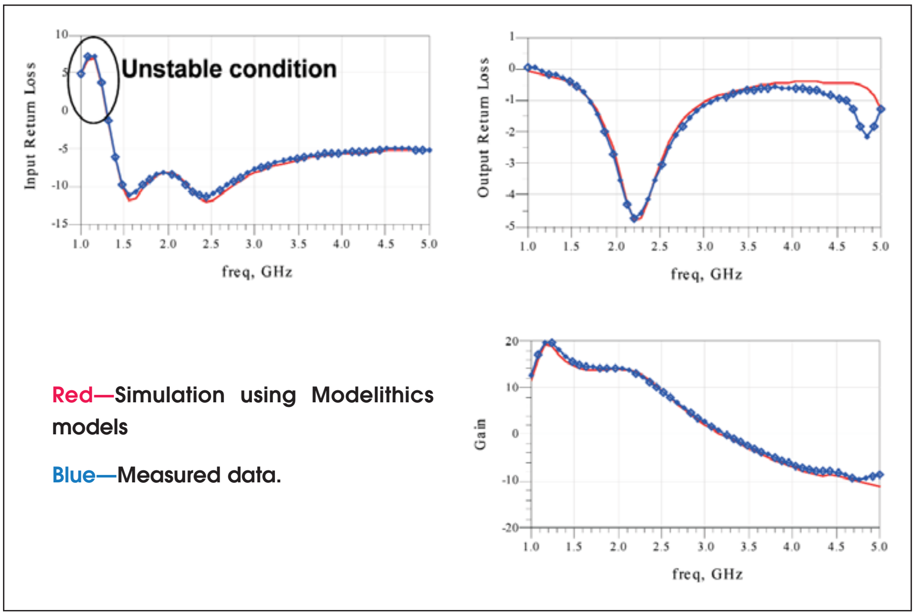

Figure 6 · 5 mil FR4 LNA circuit results. Some component values were changed from the 14 mil design to optimize matching.

changed from a single capacitor to a parallel resistor and capacitor. Figure 8 shows the simulated and measured performance of the modified circuit. The instability at the lower frequency has been eliminated, while maintaining good matching and gain performance.

Summary

This example has demonstrated a useful simulation and model strategy for translating reference designs, from one frequency, board type or component set to another. The strategy shown utilizes Modelithics Global Models for the passive ele-

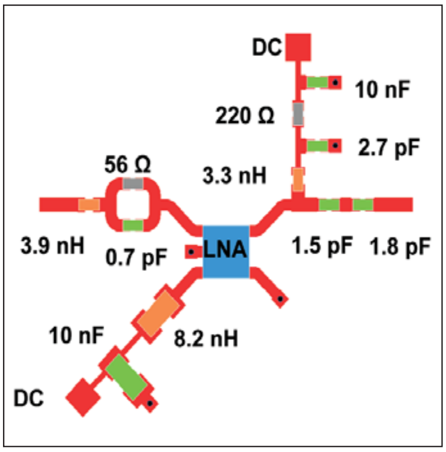

Figure 7 · Modified circuit with improved stability, derived from simulation using CLR Library component models.

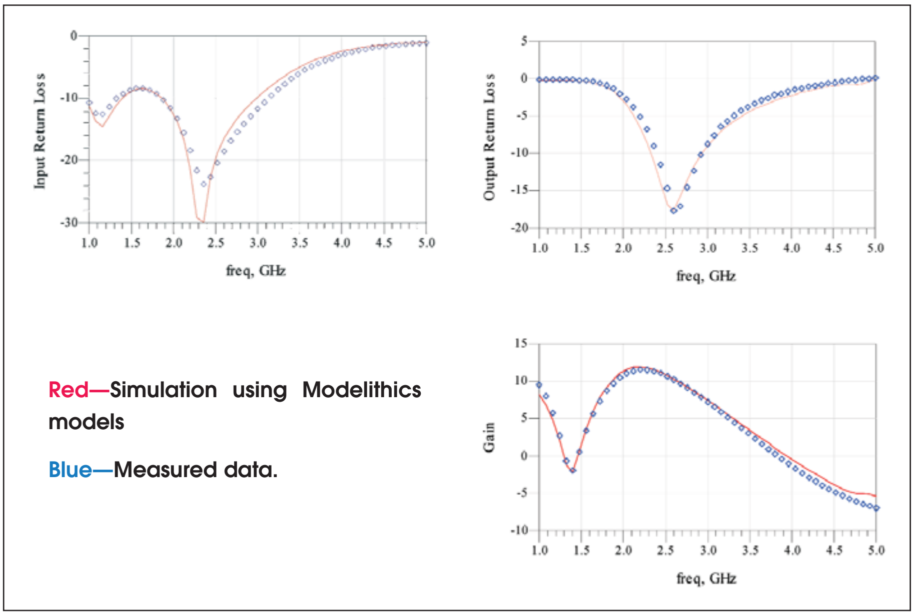

Figure 8 · Simulated and measured results for the stabilized RFIC amplifier design, optimized for 2.3 GHz.

ments combined with measured S-parameter data taken for the packaged LNA in the intended application substrate environment, to establish an accurate and flexible simulation model for all portions of the circuit. Equipped with such a model for the reference design, the engineer can proceed to rapidly change the topology, stabilize the circuit, optimize the design and develop a bill of materials for best manufacturability for the desired end-use application.

With scalable parameters, the models allow the engineer to examine the effects of various layout, substrate and component choices, to obtain the desired final design. In the example shown, it was also possible to modify the circuit to eliminate a region of instability at frequencies below the design center frequency.

Acknowledgements

The authors would like to thank University of South Florida students Sonoko Akamatsu and Alex Taningco for their assistance with this work.

Author Information

John Capwell the BSEE and MSEE in 1999 and 2003 respectively degrees from the University of South Florida. He is a member of the technical staff at Modelithics Inc. and has research interests in microwave measurements, active and passive modeling, filter, attenuator and amplifier design.

William J. Clausen received the BSEE and MSEE degrees from the University of South Florida in 2003. He is a member of the technical staff at Modelithics Inc., with research interests in the area of microwave measurements, active and passive component modeling, and amplifier design.

Tom Weller received the BS, MS and PhD degrees in electrical engineering from the University of Michigan in 1988, 1991 and 1995, respectively. He is an Associate Professor in the Department of Electrical Engineering at the University of South Florida, and a member of the Wireless and Microwave (WAMI) Center. He is a co-founder of Modelithics, Inc.

Lawrence P. Dunleavy received the BSEE degree from Michigan Technological University in 1982, and the MSEE and PhD degrees in 1984 and 1988, respectively, from the University of Michigan. In 1990 he joined the Electrical Engineering Department at the University of South Florida, where he holds the title of Professor. Dr. Dunleavy is a Senior Member of IEEE and is very active in the IEEE MTT Society, and the Automatic RF Techniques Group (ARFTG). He is a co-founder of Modelithics, Inc.

Interested readers should contact John Capwell by e-mail at jcapwell@modelithics.com or by telephone at 813-866-6335.

Capwell

Clausen

Weller

Dunleavy