WHITE PAPER

Accurate System Level Design with Low Noise Amplifier's BlackBox Models

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To amplify weak signals received by the antenna in communication systems, low noise amplifiers (LNAs) are deployed. LNAs are used in various applications such as GPS receivers, wireless data systems, satellite communications, cellular handsets, radio systems, etc. The low noise in the receive chain is reduced by the gain of the LNA, and therefore the function is primarily to boost the signal power while adding minimum noise and distortion to the signal. Low noise figure (NF) therefore results in improved reception of the received signal.

Today's commercial system designs in the RF/microwave industry are becoming increasingly complex. Part of this complexity is due to the constant strive for complete mobility and high data rates requiring portable devices to operate on various communication bands and standards while using the existing infrastructure. In turn, the increased complexity has pushed RF designers to demand more evolved design tools to minimize risk and improve their chance of first pass success. The issue is that a simulation can only be as accurate as the weakest model used for the simulation.

Following LNAs importance in the communication system chain, it is very important to simulate their performance well at a system level design. A system level design may comprise of many discrete as well as integrated drop-in components which requires careful monitoring of individual components from different suppliers. The contribution from each component is distinct and therefore the overall system level simulation demands quick effective performance look-up models of these individual components. Therefore keeping in mind the complexity handled by our customers, we have developed BlackBox models for Skyworks' MMIC product portfolio in enhancement mode (E-mode) pHEMT LNAs. Our customers can insert these BlackBox models of any of our LNAs into their system level simulations and predict the small/large performance. They may also evaluate the advanced design system (ADS) project provided with the BlackBox models which comprises the application board simulation and verify measured vs. simulated data of the respective LNA.

Presented here is the procedure we follow to produce such effective BlackBox models to predict close to accurate performance of these LNAs. We will provide basics on how to setup models in system level simulation which would give enough insight on the performance of these discrete or integrated LNAs in the system without dealing with any complex modeling setup. We will use SKY67151-396LF as a discrete LNA to demonstrate the BlackBox model setup and performance validation with the measured results in a 50-Ohm system.

Modeling Background

Scattering parameters (S-parameters) are the simplest way to describe the RF behavior of a component over frequency under any simulation platform. Although S-parameters are used for simulations, their origin being measurement based makes them ideal as they allow inserting the real measured data into simulation conveniently. S-parameters can also be supplemented with noise parameters giving a complete small signal linear simulation model. On the other hand, standard S-parameters lack any description of the large signal behavior and cannot be used to simulate the non-linear performance or describe the harmonic content generated by the device under test (DUT). Large signal S-parameters are a bit of an exception as they can describe the monotonic compression performance of a DUT through the use S-parameters function of input power, but still lack harmonic content. Another disadvantage of S-parameters is that they only describe the DUT under a single bias condition. Therefore providing bias flexibility is equal to providing a compiled set of S-parameter files describing every bias point.

The relationship between the input and output of a device can also be expressed in the form of an equation. The equation based linear/non-linear models can describe with good accuracy the simple responses and basically involves fitting a set of electrical variables or coefficients to the measured or expected response. A good example of a device well suited for this type of modeling is a diode. As the devices get more complex, this modeling method quickly falls short in describing RF performance accurately.

Simulation program with integrated circuit emphasis (SPICE) models are widely used by integrated circuit industry for circuit simulation prior to fabrication. SPICE models are capable of predicting a semiconductor's performance both in the linear and non-linear range of operation and are standardized through the compact model council. Standard SPICE models enable the simulation of the same problem by various software platforms although some may choose to use proprietary models. These SPICE model will typically focus on a distinct element of a circuit such as a transistor, a non-linear resistor, etc. The simulation of a more complex design or system is then achieved by interconnecting the distinct elements together in a schematic. Allowing the simulation by a third party of a complex circuit topology using multiple SPICE elements opens up an intellectual property problem as the manufacturer must share its schematic as well as the characteristics of its technology.

Recently, Agilent Technologies introduced X-parameters to the RF/microwave industry. In some aspect X-parameters are similar to S-parameters in the sense that they primarily are a measurement based description of a circuit's response, but differ where they account for the harmonic content as well. The inclusion of the harmonic content allows the modeling of non-linearities. In a passive or perfectly linear device, X-parameters reduce to S-parameters. But similar to S-parameters, X-parameters only describe a DUT under specific conditions of operation. Simulation flexibility is achieved by characterizing a DUT under numerous bias conditions which may produce massive datasets.

BlackBox Model

Skyworks has chosen to supply models of its infrastructure LNAs through ADS compiled BlackBox models. A BlackBox model refers to providing a fully modeled schematic symbol of a device without revealing its content. BlackBox models can offer numerous advantages to both the customer and the manufacturer. First they allow the use of previously discussed modeling options for any portion of the design as it fits best to the measured data, including electromagnetic simulation (EM) results. Especially when integrated modules are present, EM is rigorously performed including the bond wires between interconnects. As the BlackBox model is compiled and provides some level of intellectual property (IP) protection, the available modeling options also include Skyworks' proprietary model libraries. In other words, the BlackBox models enable customers to get the exact same simulation results as the designers of the device, even if the eventuality proprietary models were used. Skyworks has a wide range of proprietary models available to its designers to enhance simulation accuracy. Also, as the same models are used for design and customer simulations, BlackBox models are easier on company resources as a single set of models that has to be maintained. The BlackBox model simply has to be compiled again to benefit from updated model libraries. Finally, they are also easy to use by the customer as they are implemented in the form of a component from the component palette in ADS.

BlackBox Model Design

The black box model generation effort typically starts once a proper design variant has been selected and characterized for production. The designer's simulation are compared with the characterization data and adjusted for the best fit. As a first step, the board and the bill of materials are updated so they correspond to what was used for the measurement. Following which, are reasonable parasitics added at the respective frequency or adjusted at both the schematic and device levels to improve the fit with measured data. Once a reasonable fit has been achieved the DUT description of the device is compiled, added back to the schematic and the project is compressed (*.zap file). Figure 1 shows the block diagram of the BlackBox model proposed, which encloses the LNA modeled die on a package with wire bonds for RF and DC lines.

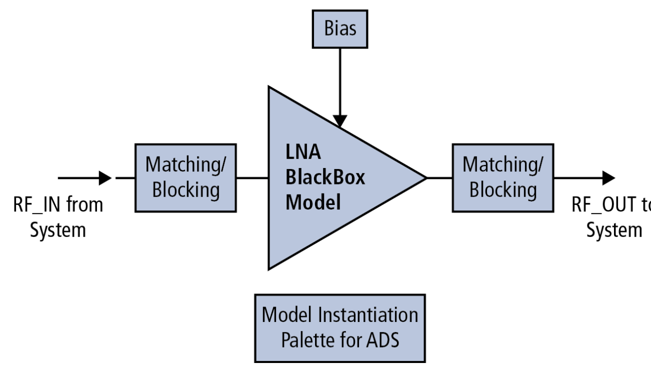

Figure 1. BlackBox Model in ADS

Once installed, a Skyworks BlackBox model has three components: the DUT, a schematic, and a simulation setup. The DUT is the compiled portion, the BlackBox itself, while the schematic and the simulation illustrates how to use the DUT in simulations. The DUT includes die and package level models such as wirebonds, etc. The schematic is typically a model of the application board shown on the datasheet and used for the characterization of the part. The schematic of the board is modeled using available ADS transmission line models and accounts for the substrate characteristics and physical dimensions of the layout. The surface mount components are modeled using the manufacturer supplied SPICE parameters. The use of SPICE models for inductors and capacitors offers the advantage of predicting very high frequency out of band performance such as the stability while providing reasonable accuracy at the normal frequency of operation. Manufacturer supplied S-parameters may offer better accuracy within the band of operation but may fail to predict far out of band high frequency performance simply because they are often not characterized that far. For example, it is not uncommon for a capacitor manufacturer to supply S-parameter data up to only 6 GHz which will put the simulation in an unbounded extrapolation mode without any warning to the user if that frequency is exceeded. It is therefore extremely important to verify each S-parameter file for its maximum frequency point before it is used in a circuit. The simulation portion of the schematic simply sets up all common simulation parameters so the user only has to run a simulation in order to get results. Figure 2 illustrates the package level schematic used for the top level BlackBox model.

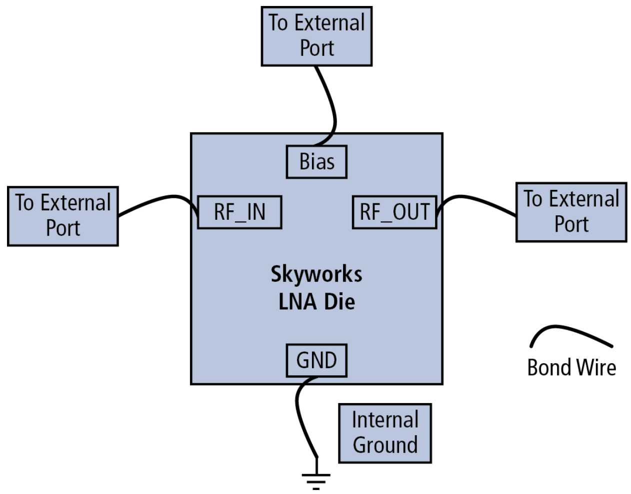

Figure 2. Inside the BlackBox Model

The LNA die level schematic shown in Figure 2 is encoded with ADS. For convenience to match with modeled data, we are using ADS 2009. The encoding is performed in such a way that the Skyworks LNA models are fully functional inside the BlackBox model and can simulate the active and passive devices inside the module effectively. Also external to the LNA die we have models that will simulate the bond wire modeled which will also be encoded along with the other designs. However, before encoding we ensure that the small/large signal performance is close to the measured data. The parasitic effects are also included in the design at the respective LNA's frequency of interest.

To provide an example on the accuracy of the BlackBox model, we will highlight the small signal comparison from our latest SKY67151-396LF in Figures 3–6. Similarly the noise figure (NF), large signal, and DC performance from the SKY67151-396LF have been compared to the BlackBox model which is tabulated in Table I. From one LNA design to another, the models are matched close to the measured data with ADS design setups and EM setups.

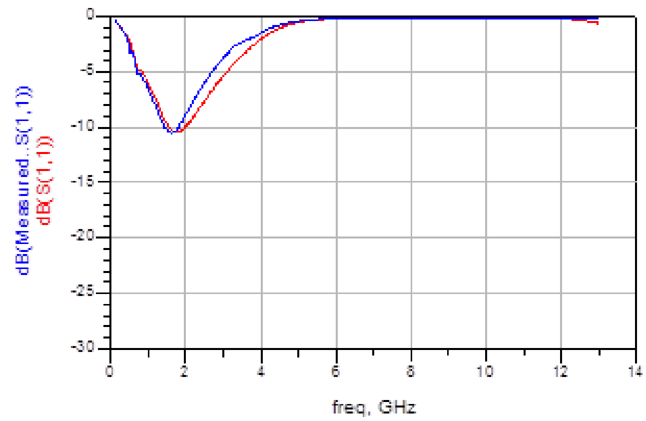

Figure 3. Measured Data (Blue) vs. Modeled Data (Red) for Input Return Loss

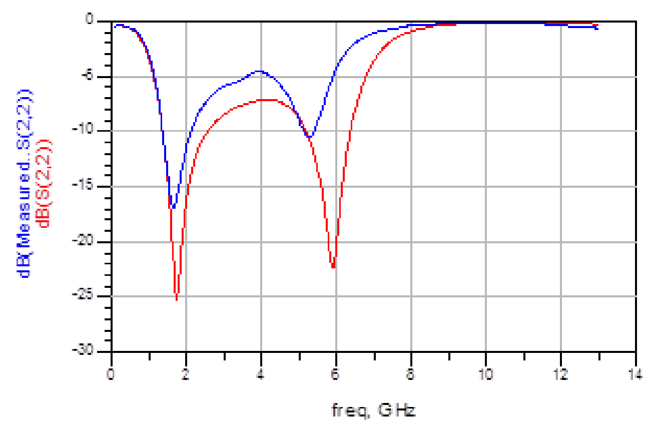

Figure 4. Measured Data (Blue) vs. Modeled Data (Red) for Output Return Loss

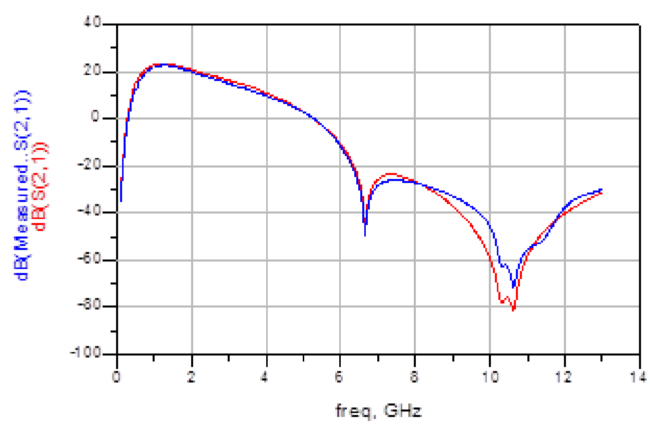

Figure 5. Measured Data (Blue) vs. Modeled Data (Red) for Gain

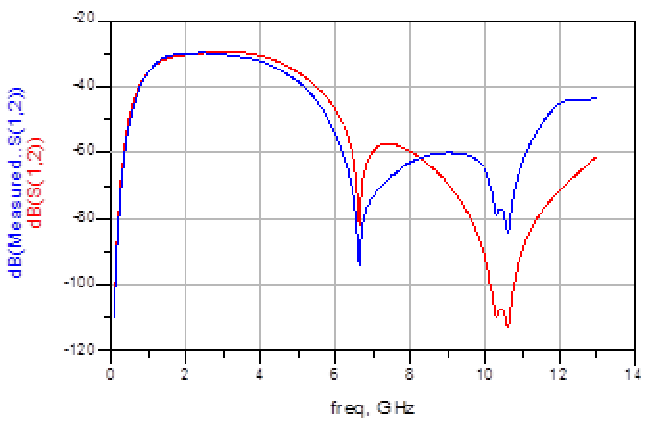

Figure 6. Measured Data (Blue) vs. Modeled Data (Red) for Reverse Isolation

Table I. The SKY67151-396LF BlackBox Model vs. Measured Data

Parameter @ 1.9 GHz	BlackBox Model	Measured Part	Unit
Noise Figure	0.27	0.30	dB
Output Third Order Intercept Point	36.14	36.00	dBm
Input Third Order Intercept Point	14.82	15.50	dBm
Output 1 dB Compression Point	-1.00	-0.50	dBm
Input 1 dB Compression Point	19.5.	19.00	dBm
Supply Voltage	5.00	5.00	V
Quiescent Supply Current	76.00	70.00	mA

BlackBox Model Setup

After encoding the LNA to top level design which can be combined with the EVB simulation to receive the appropriate performance, we archive the encoded model for customers to use. For example, the SKY67151-396LF is archived as the SKY67151_2009.zip. This can be kept at the working directory of ADS 2009 or in any folder on the working C:\ drive. For convenience, we are using C:\users\default as the home directory for ADS. We will also provide an ADS archived project file to run the top level EVB simulation for convenience. We are using the SKY67151_BB_Sim.zap as the archived project for explanation. Please make sure that this compiled model runs only on PCs, so the design kit can only be used on a PC platform with ADS 2009. The procedure for setting up the model is very simple and takes a few steps which follow. Figures 7–10 will illustrate the steps.

1) Click on Design Kit on the ADS Main Window, and select Install Design Kits, Figure 7.

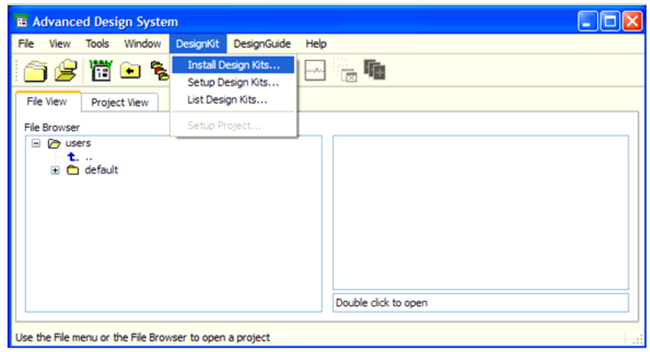

Figure 7. Setup Design Kit on Ads Main Window

2) A pop-up window appears, click on Unzip Design Kit Now, Figure 8.

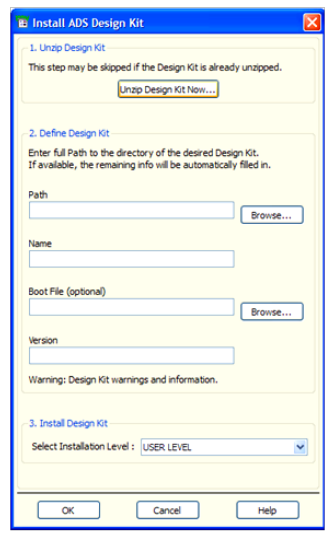

Figure 8. Unzip Archived Model

3) Locate the SKY67151_2009.zip at the project location and click Unzip Design Kit Now. After it unzips the folder, it will automatically fill the rest required paths, Figure 9. Click OK to proceed.

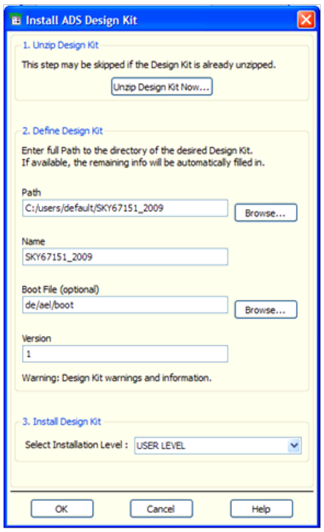

Figure 9. Archived Model Path Setup

4) Un-archive the SKY67151_BB_Sim.zap project folder in the same directory. Now there should be four folders in the directory—two for ADS projects, and two for the BlackBox models, Figure 10.

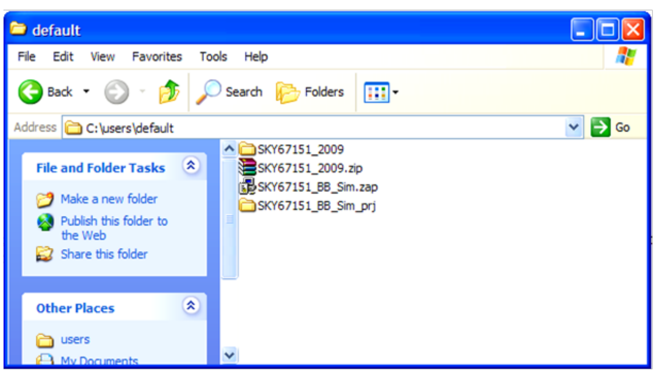

Figure 10. Folder View of Model and Project

5) The encoded design is in the SKY67151_2009 which will be used in the SKY67151_BB_Sim_prj project.

6) In the project design will be the Netlist Include component (already placed) where the model path needs to be changed to be the same as the installation directory (find the path for models.net file). If using a new design, click on menu Dynamic Link and choose Add Netlist File Include, Figure 11.

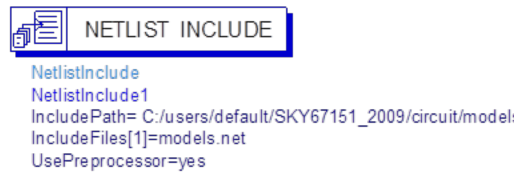

Figure 11. Netlist Include Component Placement with Correct Path

7) In the ADS schematic window, we should see a palette with the SKY67151_2009 BlackBox Model which can be used in the schematic with the Netlist Include component, Figure 12.

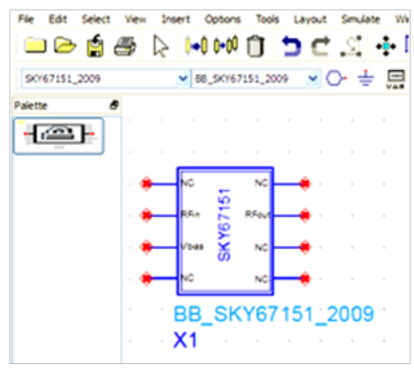

Figure 12. BlackBox Model from Ads Palette

The BlackBox model is ready to be used now at any design hierarchical level and any system level design simulation.

Conclusion

We have presented the SKY67151-396LF LNA's BlackBox Model implementation and setup. These models can also be cascaded, if desired in a system level design. The BlackBox Model presents the SKY67151-396LF's industry leading noise figure with other excellent gain, isolation, return loss, and large signal characteristics. With the complexity of the design at a system level, these BlackBox Models satisfy customer's demand for quick and accurate simulation. It envelops the demand for a controlled system level design, bypassing definitions of complex LNA discrete components. This model highlights Skyworks' MMIC product portfolio in enhancement mode (E-mode) pHEMT amplifiers with industry leading noise figure performance.

For more information, please visit www.skyworksinc.com.