Techniques for Small-Signal Modeling

Designers should remember to include stability and maximum available gain in their models

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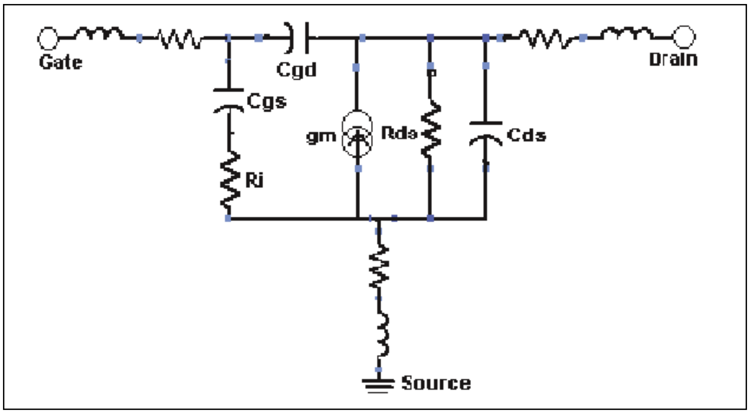
In small signal modeling, the perennial wisdom is that if you can match the *S*-parameters, then you will have an excellent model. However, this is not always the case. The input and output reflection coefficients, along with the stability factor *K* and the maximum available gain, are also very important optimization goals for a model. These goals are rarely met for a typical small signal model.

Matching the *S*-parameters from data can be accomplished through optimization of intrinsic and extrinsic elements. This created model may not be accurate; the maximum available gain and *K* may not meet with the data's characteristics. Therefore, watching these parameters allows for a more accurate model. Adding reflection coefficients, max gain and *K* as goals allows the model to be as precise as possible. In the past, a model would be generated without any knowledge of the reflection coefficients, maximum gain or *K* and sent on to a designer. Any credible designer would automatically label it as unreliable and not use it for designing.



▲ **Figure 1. Small-signal transistor equivalent circuit model.**

Modeling procedure

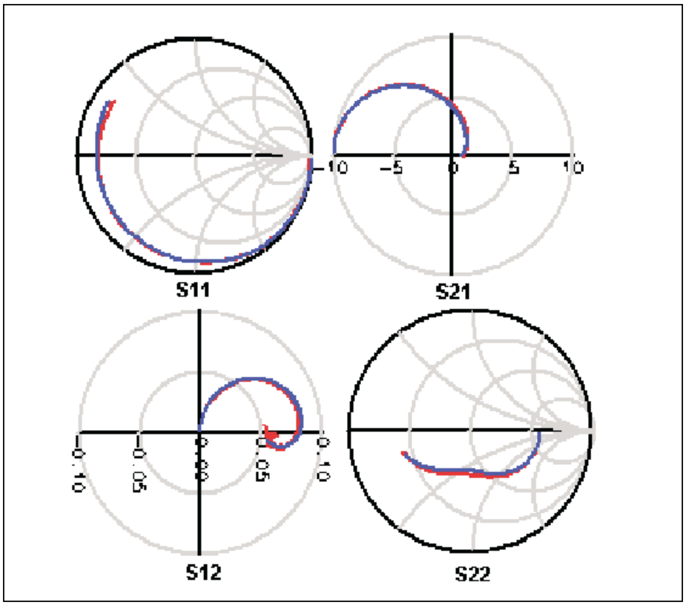
From a modeler's standpoint, there is a fine line between a good model and an accurate one. Small-signal modeling starts by looking at the equivalent circuit (Figure 1). Starting with measured *S*-parameter data, the first step is to use parasitic values calculated by commercially available software, such as Agilent's ICCAP, for a test device. For this example, a PHEMT device was used at a drain voltage of 2.5 V and a gate voltage of –0.7 V.

Next, an in-house extraction program was used to generate starting values for the intrinsic elements:

g_m = 157.72 mS
Tau = 1.71 oms
R_i = 0.81 ohms
R_{ds} = 155.01 ohms
C_{ds} = 148.15 fF
C_{gd} = 49.59 fF
C_{gs} = 664.18 fF

Commercially available simulation software such as Agilent's Advanced Design System 1.1 is then used to optimize the model using *s*-parameters only, as the goals. The new intrinsic values are:

g_m = 155.2 mS
Tau = 0.8 ms



▲ **Figure 2. *S*-parameters, red = data, blue = model.**

R_i = 1.85 ohms
R_{ds} = 180.3 ohms
C_{ds} = 150.5 fF
C_{gd} = 62.0 fF
C_{gs} = 662.7 fF

Figure 2 shows that the *S*-parameters were matched very well, but Figure 3 shows that the reflection coefficients, max gain and *K* for this model are not as accurate. So by logical deduction the next process is to model these indicators as well as the *S*-parameters.

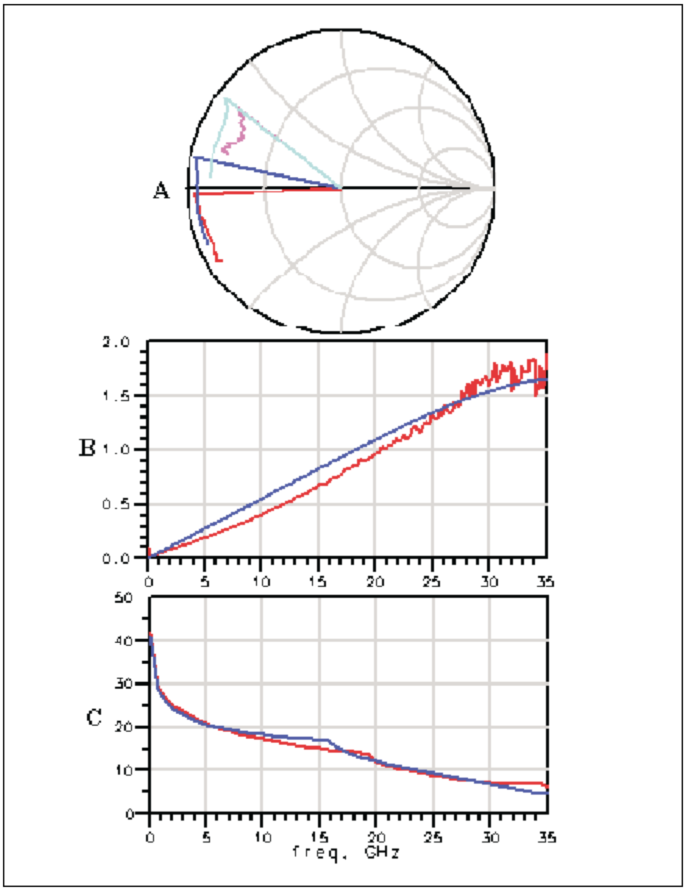
The new procedure is to add optimization goals for reflection coefficients, maximum available gain and stability factor *K*. The equation goals for ADS are:

Stability Factor, K
K_ratio = our_k/our_k2
(our_k = data's *K*, our_k2 = model's *K*)
with this ratio goal set to a magnitude of 1.

Maximum Available Gain
maxg_ratio = our_maxg/our_maxg2
(our_maxg = data, our_maxg2 = model)
with this ratio goal set to a magnitude of 1.

Input Reflection Coefficient
smg1_ratio = our_smg1/our_smg1_2
(smg1 = data's, smg1_2 = model's)
with two ratio goals, one for magnitude set to 1 and another for phase set to 0.

Output Reflection Coefficient
smg2_ratio = our_smg2/our_smg2_2
(smg2 = data's, smg2_2 = model's)
with two ratio goals, one for magnitude set to 1 and another for phase set to 0.

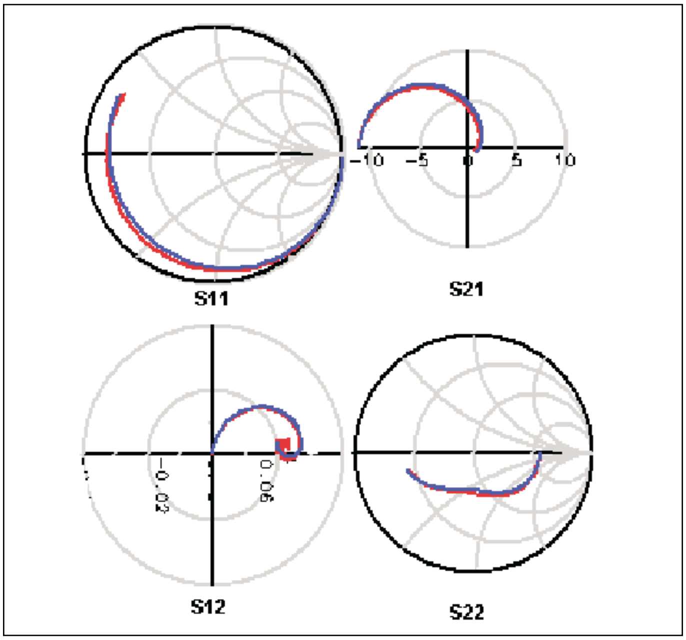


▲ **Figure 3. (A) Reflection coefficients, red = input for data, blue = input for model, pink = output for data, light blue = output for model. (B) Stability factor, *K*, red = data, blue = model. (C) Max available gain, red = data, blue = model.**

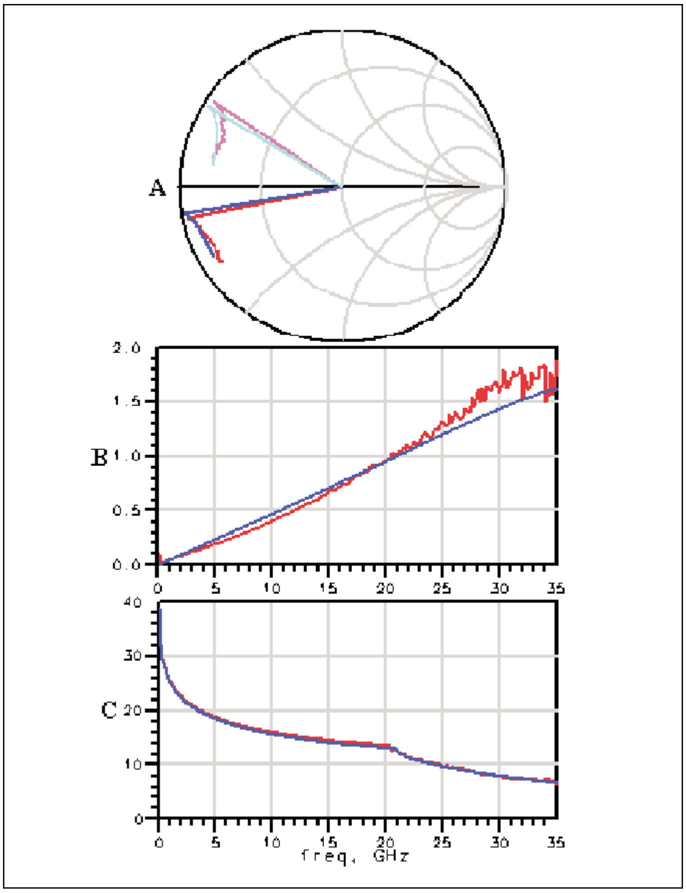
Now the small-signal modeling procedure is started all over again. Extracting the original data gives the same starting points for the intrinsic values, but now optimizing the *S*-parameters with the reflection coefficients, max gain and *K* as added goals. This gives the following value for the intrinsic elements:

g_m = 145.1 mS
Tau = 0.4 ms
R_i = 0.15 ohms
R_{ds} = 160.3 ohms
C_{ds} = 110.0 fF
C_{gd} = 54.0 fF
C_{gs} = 652.0 fF

Figure 4 show the new *S*-parameters and Figure 5 shows the matched coefficients, gain and *K*. As displayed, it takes only slight adjustments of the elements to match our goals.



▲ **Figure 4. *S*-parameters, red = data, blue = model.**



▲ **Figure 5. (A) Reflection coefficients, red = input for data, blue = input for model, pink = output for data, light blue = output for model. (B) Stability factor, *K*, red = data, blue = model. (C) Max available gain, red = data, blue = model.**

Application example

A good example to illustrate the importance of reflection coefficients is the design of a simultaneously conjugent match amplifier. The process in designing this type of amplifier starts by taking the device data or model and matching the input and output reflection coefficients. If the designer uses a model that has not properly matched the reflection coefficients, then their amplifier when simulated, will not attain the maximum gain and in production will be an inferior device.

In the case of a matched amplifier the model's reflection coefficients are the most important characteristics. Without this parameter, a designer will have no need for a small signal model; all the elements will have a higher degree of inaccuracy.

Conclusion

In short, small signal modeling has been a somewhat inaccurate field of study from the point of view of a designer. However, this paper hopes to show new techniques that will add the proper indicators and optimization goals to the modeling procedures to give the most accurate and credible model possible. ■

Note

All graphs and optimizations were computed and produced by Agilent's Advanced Design System 1.1 with support from Agilent's ICCAP 5.0.

References

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2. G. Dambrine, A. Cappy, F. Heliodore, E. Playez, "A New Method for Determining the FET Small-Signal Equivalent Circuit," *IEEE Trans. Microwave Theory Tech.*, Vol. 36, July 1988.

Author information

This research was completed by COMSARE, the Center of Microwave/Satellite and RF Engineering, at Morgan State University in Baltimore, MD. Participating in the research were John Brice, Christopher Giusto, Clifton Martin, Jerhome Petway and Ammyanna Williams. This undergraduate unit is under the leadership of Dr. Carl White and Willie Thompson, along with the rest of the COMSARE team. More information on COMSARE is available on its Web site, http://www.eng.morgan.edu/~comsare.

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