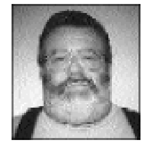
Ron Mancini, Harris Semiconductor



Design Feature

Don't count on your Spice models until you validate them

Op-amp Spice models are widely used to simulate circuit performance, but they are not perfect. You can use these models, but you shouldn't fully trust them unless you've tested the model vs the actual device.

There are several reasons for this situation. Spice is a computer program, subject to all the vagaries of a machine/software package. Also, the Spice model is an approximation, and you can't trust approximations until you understand them and their limitations. Before you use a Spice model, you should test it in a known circuit and see how the results compare to the op-amp data sheet.

You can use the test approach, procedure, and programs described here to judge op amps and their models. This example uses Spice models from four major current-feedback-amplifier manufacturers. Even if you are not going to use one of the specific op-amp models tested, you can apply the technique to obtain indications of the validity of the models in your application.

Begin with a program

Reference 1 contains a standard set of PSpice programs that that were used in this example of model testing. The inverting-gain, noninverting-gain, and transient-response programs were selected for model testing because they yield data adequate for a model-vs-data sheet comparison. The application note contains six programs that cover most op-amp parameters. You can use almost any program for the evaluation, but the program must use the op amp in the same configuration as the data sheet. The application note is a useful tool because it allows you to incorporate the data-sheet operating conditions. In addition, it runs three parallel circuits and automatically normalizes the data for three gains (inverting or noninverting) in one pass of the program.

The program you use must allow you to select relevant component values, such as the feedback resistor, so that you can perform the evaluation at the data-sheet conditions. A valid comparison between the device and its data sheet has this requirement be-cause you must evaluate the op amp at the exact data-sheet operating conditions. This approach allows you to match the Spice-generated data and curves to those on the data sheet. For a good comparison, you need to consider the feedback resistor, input and output terminating resistor, load resistor, load capacitor, and gain-setting resistor values, as well as the power-supply voltage.

The goal is to determine how closely the model matches the op amp as in the manufacturer's data sheet. You are not trying to characterize the op amp. Although you may find a better method to characterize the op amp--this is good information for future use--it is not part of evaluating the model.

The data-sheet curves in the model test were obtained from measurements made on a "typical" IC. These curves are repeatable to only a few percent because of the difficulties of measuring current-feedback op amps. Because the model approximates IC performance, it's normal to expect some differences between the curves the model produces and the vendor-provided data-sheet curves. For this reason, you can use tolerances to account for these differences.

The comparison criteria come from conversations with design engineers. This example considers peaking matches to within 2 dB to be a good correlation and peaking in excess of 2 dB to be marginal. Although the best case is when the data sheet matches the model results, the data-sheet peak values should be less than the model peaks because this approach is less likely to lead the designer to optimistic conclusions. (Peaking causes an emphasis of the high frequencies in the signal and often leads to distortion.)

Bandwidth correlation within 20% of the model to the data sheet is acceptable. Data-sheet bandwidth greater than the model bandwidth is preferable because using the data-sheet bandwidth leads to conservative design. Transient-response correlation should be within 20%, but this parameter is secondary to the peaking and bandwidth. It is difficult to get good transient response from a model, so many model designers sacrifice this parameter in favor of the frequency-response plots.

This evaluation uses four op amps: the Harris (Melbourne, FL) HA5013 (A), Analog Devices (Norwood, MA) AD811 (B), National/Comlinear (Sunnyvale, CA) CL414 (C), and Linear Technology (Milpitas, CA) LT1229 (D). They were selected for their availability, current-feedback architecture, available Spice models, similar bandwidths, and similar remaining parameters. The models were not reviewed to determine whether one model appeared to be superior to another. You can use other products to perform your own comparison.

The conditions for each test are the same as those on each data sheet. At first glance, this may seem unfair because one vendor tests with a 10-pF, load and another does not specify a load capacitor, but, because you evaluate each model against its own data sheet, this comparison is fair. Table 1 shows the load conditions for each op-amp comparison. A separate simulation with a small capacitive load was run for each op-amp model to check for instability. The table also summarizes the results of the noninverting-gain evaluation.

Figure 1 shows the noninverting results for all four devices, without capacitive loads. For op amp A, these indicate 0.7 dB less peaking than that on the data sheet, as well as 5 MHz less bandwidth than that on the data sheet. Both of these numbers are well within the comparison criteria, so it is reasonable to assume that the model well represents the IC for the noninverting-gain configuration. The B model has 2.3-dB peaking, and the data sheet shows 0-dB peaking. The model bandwidth is 9 MHz less than the data-sheet bandwidth. This performance is marginal for the model, but, if you use this bandwidth to evaluate a circuit, the results are conservative, so the design should be safe.

This model also shows a spike in the frequency response at 900 MHz when you add a 4-pF load capacitor to the circuit. If the spike is just an artifact that the model produces, the spike may have no effect on the actual circuit performance, but if the spike shows up in the IC-transfer function, the spike can cause high-frequency oscillation. You must further investigate the spike before you can be comfortable with the IC and the model. The data sheet shows a considerable difference between the frequency-response curves at ±15 and 5V power-supply operation. However, the Spice-model analysis shows no difference between these curves, so, without further information, you should assume that the model excludes effects due to power-supply variations.

Device C's model has 2 dB of peaking compared with the data sheet's 0-dB peaking, and the model bandwidth is 210 MHz vs the data-sheet bandwidth of 70 MHz. The difference in the peaking numbers is within the criteria, and the high number is in the model and so is acceptable. The bandwidth difference is so large that the model may be unusable because it predicts overoptimistic results. Also, the model may need some help; sometimes, these models need the addition of external components to aid convergence or measurements. It's a good idea to contact the manufacturer's application department before proceeding with a design based on this model.

Adding 4-pF load capacitance to Device C increases peaking about 1dB, and the 3-dB bandwidth increases approximately 7% when you add the load capacitor to the circuit. This operation is normal for a current-feedback amplifier, and you can counter it increasing the feedback resistor by a few percent (Reference 2).

The Device D data shows a model with a 0.8-dB dip and a 0.2-dB peak. The resultant error, 1 dB, is acceptable. The model bandwidth is 120 MHz, and the data-sheet bandwidth is 102 MHz. This bandwidth does not meet the evaluation criteria; furthermore, the model predicts a much better high-frequency performance than the IC can deliver. You must factor this performance into your calculations.

Adding a 4-pF load capacitance to the D model increases the dip by about 0.4 dB, and the 3-dB bandwidth increases about 12%. Again, this performance is normal and compensatable operation in a current-feedback op amp. The data sheet predicts a bandwidth change from 102 to 60 MHz when you change the power supplies from ±15 to ±5V, but the model shows a bandwidth change from 120 to 60 MHz. For this reason, you may need to carefully examine the model before designing with it. With 15V supplies, you have to be concerned about getting optimistic results, but, with 5V supplies, the design results should be on target. This example of a Spice model includes a supply-voltage-dependency function.

The conditions for testing inverting op amps are the same as those on the vendor data sheets. Table 2 shows the load conditions for each op-amp comparison and summarizes the results of the inverting-gain evaluation. Device D's data sheet omits inverting-gain curves, so this evaluation excludes Device D.

The model for Device A indicates 1 dB less peaking and 15 MHz less bandwidth than that on the data sheet. Both of these numbers are well within the comparison criteria, so you can assume that the model is a good representation of the IC for the noninverting gain. The model's bandwidth for the gain-of-10 configuration is 70 MHz compared with a data-sheet bandwidth of 22 MHz; thus, this model yields overoptimistic answers at high inverting gains. If you have to make a compromise, it is usually at high inverting gains because this area is where current-feedback amplifiers are the least used.

For Device B, the 0.8-dB peaking of the model closely matches that on the data sheet, which shows no peaking. The model does have 2.3-dB peaking when the model is in a gain-of-10 configuration. You may need to make allowances for this error, depending on what gain values you use. Again, the model compromise is at high inverting gains. The model bandwidth matches that of the data-sheet bandwidth.

The C model indicates 0.3 dB of peaking and is well within the comparison criteria when compared with the 0.8-dB peaking on the data sheet. The model bandwidth is 180 MHz compared with the data-sheet bandwidth of 97 MHz, so the model predicts overoptimistic frequency performance. The 10-dB performance of this model is excellent, which proves that not all models push their poor performance into the high-inverting-gain configurations.

Time-domain testing

You can evaluate each op amp using a ±100 mV square-wave input signal to determine its small-signal, time-domain response. If there is a photograph of this response in the data sheet, you can compare the photo with the model to find how well the PSpice simulation mirrors the time-domain response. If no photograph is available, this data still has value because you can compare it with the theoretical time-domain response as calculated from the second-order, transfer-function equation (Reference 3).

Figure 2 shows the small-signal pulse response—which is equivalent to the time-domain response—for Device A. Both the model and the data sheet show a few percent of overshoot, which is a good correlation. For Device B (Figure 3), the PSpice program did not complete the analysis because the time-domain response never settled down. The program chose the time-step size according to the activity of the response, and B's active response dictated the use of a small time step, which resulted in too many calculations. The time-domain response overshoots the final value by 160 mV for a 200 mV step. This procedure is an almost-complete reflection of the input step and is very unusual.

This phenomenon may be related to the spike in the noninverting-frequency-response curve. Regardless of the spike's source, you should investigate and resolve this effect before using the model for time-domain analysis.

Figure 4 shows the small-signal pulse response for Device C. The model overshoots by 100 mV, and it settles out in 30 msec. You cannot compare the model to the figure on the data sheet because there is no photograph of the small-signal pulse response in the data sheet. To determine whether to trust the model's transient response, you have to test the op amp and compare the test results to the model results. However, considering the large amount of overshoot and the bandwidth results, this comparison may be a wasted effort.

Figure 5 shows the D Device small-signal pulse response. The model overshoot is 85 mV, and it does not settle out for 43 nsec. The small-signal rise time in the data sheet has little overshoot. The model overshoot is much more than you would expect from an op amp that has little peaking in its frequency-transfer function, and it seems safe to assume that the model adds overshoot to the time-domain re-sponse. You can use the model for transient analysis, but picking the model artifacts from the plots is laborious and, possibly, misleading.

No model meets the evaluation criteria in every case because the models are approximations of reality. Data sheets, which are considered to be the standard here, also contain some error. This lack of correlation between the data sheet and the models will always exist; the proof is that op-amp design engineers always complain that process models are not accurate enough. The paradox is that when the process models evolve enough to become really accurate, the process has usually aged and is becoming obsolete.

The model for Device A is the most accurate by any standard, meeting all the evaluation criteria except one. This omission occurs because the model performance standards are set first, and then the vendor constructs the model to meet the performance standards. Designing the model involves a trade-off between complexity, runtime, convergence capability, and accuracy. The A model can optimize these parameters through the use of special techniques. Device D's model is acceptable except for its transient performance. It is difficult to achieve good accuracy with the other models.

You should first evaluate any model against the data sheet. If you get excellent correlation, such as with A, you can then trust the model results. If any doubt exists about the model, use electronic-circuit theory, a good calculator, and the lab to settle the questions.

When the model performance matches that of the data sheet and both match the lab performance, the results are trustworthy. You can use such a model to predict the performance of any linear-circuit configuration that converges. e

References

1. "Evaluation Programs for Spice Op Amp Models," Harris Semiconductor AN9523 and Spice model disk.

2. Mancini, Ronald, "Converting from voltage-feedback to current-feedback amplifiers," Electronic Design, June 26, 1995.

3. Mancini, Ronald, "Feedback, Op Amps and Compensation," Harris Semiconductor Application Note 9415.

Author's biography

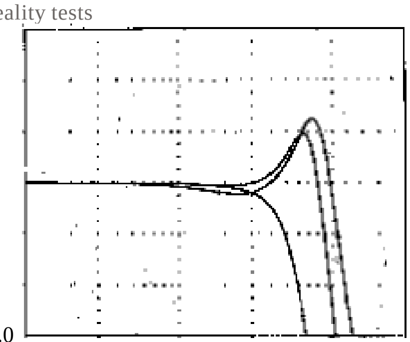
Ron Mancini is a strategic marketing manager at Harris Corp, Semiconductor Division. He has a BSEE from the Newark College of Engineering (Ne-wark, NJ) and an MSE from the University of Florida (Gainesville, FL).

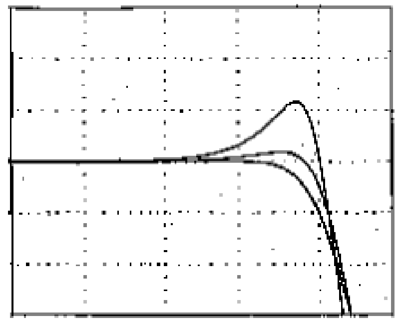
Op-amp Spice models are essential design tools, but you should perform some model-vs-reality tests to understand their accuracy.

SPICE MODELING

Figure 1

6.0





6.0

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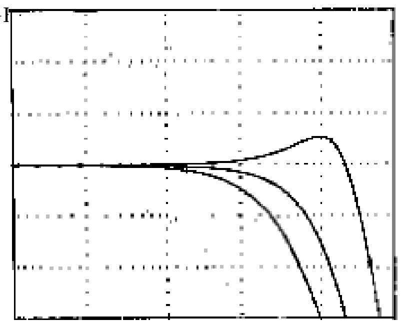
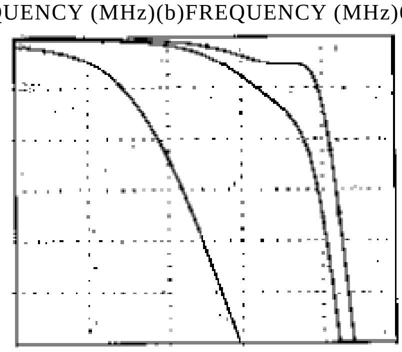


FREQUENCY (MHz)(b)FREQUENCY (MHz)6.0



0

4.0-2G=22.0-4G=2VOLTAGE (V)0VOLTAGE (V)-6G=6G=10-2.0-8G=10G=100-4.0-10-6.0-1210301003001.03.01.03.01030100300(c) FREQUENCY (MHz)(d)FREQUENCY (MHz)The inverting-mode frequency response (a through d) for devices A through D, respectively, each at three gain values, shows the range of bandwidth and peaking values that the Spice models predict.SPICE MODELINC

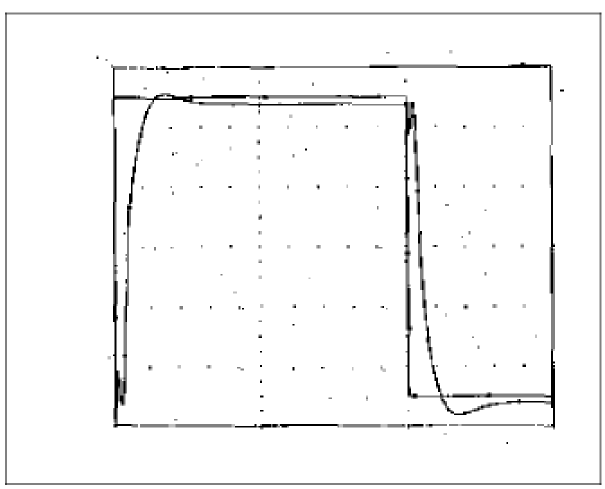


Figure 2120INPUT80OUTPUT40VOLTAGE (mV)0-40-80-120500100150RESPONSE TIME (nsec)The model's small-signal pulse response for device A shows little overshoot. Data-sheet Model

Power Load Load Feedback Data-sheet Model 3-dB 3-dB

Supply resistor capacitor resistor peak/dip peak/dip bandwidth bandwidth

Op amp (V) ((omega)) (pF) Gain ((omega)) (dB) (dB) (MHz) (MHz)

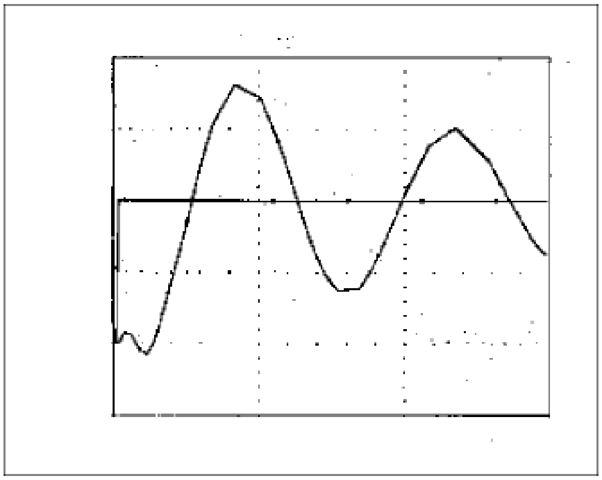
A ±15 400 10 1 1000 3.2 2.5 125 120
2 681 3.1 1.9 110 98
10 383 0 0 70 58

B ±15 150 0 1 750 0 2.3 119 110 2 649 0 0.3 115 115 10 511 0 0 100 105

C ±5 100 0 2 500 0 2 70 210
6 500 0 0 96 125
10 500 0 0 60 68

D ±15 100 0 2 750 0.2 0.8 102 120
10 750 0 0 60 70
100 750 0 0 13 7

Table 1--Load conditions and results for noninverting-gain evaluations



SPICE MODELING

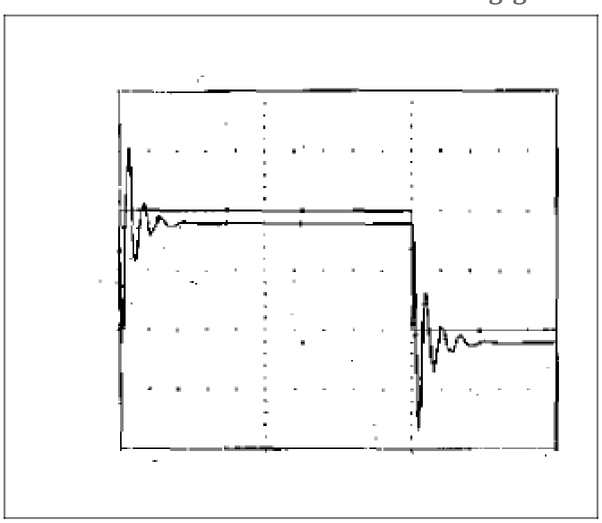
Figure 3300200INPUT100VOLTAGE (mV)0OUTPUT-100-200051015RESPONSE TIME (nsec)For Device B, the small-signal pulse response of the model did not settle, and the overshoot was large; both require more investigation. Data-sheet Model
Power Load Load Feedback Data-sheet Model 3-dB 3-dB supply resistor capacitor resistor peak/dip peak/dip bandwidth bandwidth Op amp (V) (V) (pF) Gain (V) (dB) (dB) (MHz) (MHz)

A ±15 400 10 1 750 1.5 0.5 100 85 2 750 0.4 0.6 80 80 10 750 0 0 22 70

B ±15 150 0 1 590 0 0.8 115 110 10 511 0 2.3 95 105

C ±5 100 0 1 500 0.8 0.3 97 180 5 500 0.6 0 88 98 10 500 0 0 70 55

Table 2--Load conditions and results for inverting-gain evaluations



SPICE MODELING

Figure 4300200INPUT100OUTPUT0VOLTAGE (mV)-100-200-300050100150RESPONSE TIME (nsec)You must compare the predicted small-signal pulse response of Device C to an actual measured device, because the data sheet does not have the corresponding figure.

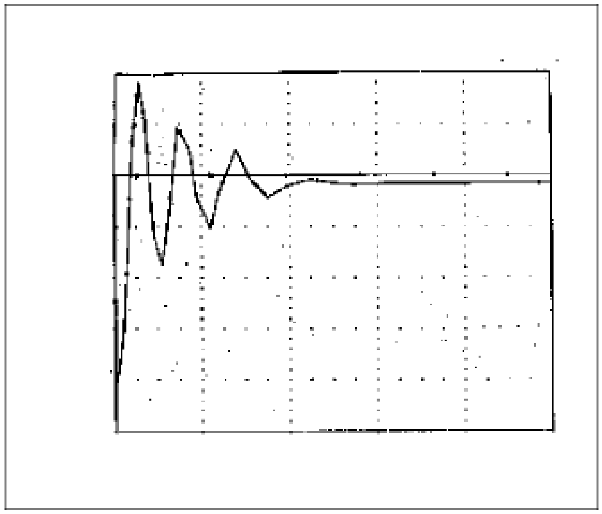


Figure 5200150INPUT10050VOLTAGE (mV)0OUTPUT-50-100-150020406080100RESPONSE TIME (nsec)The predicted small-signal pulse response of Device D appears to have more overshoot than does the actual device.SPICE MODELING