ADVANCED HIGH ACCURACY BEHAVIORAL SPICE MACROMODEL OF OPERATIONAL AMPLIFIER

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In the paper an advanced parameterized analog behavioral SPICE macromodel of operational amplifier is proposed.

The following parameters and characteristics of voltage feedback operational amplifier are modeled: frequency dependent input and output impedances; differential and common mode gains and power supply rejection ratios with their tolerances, frequency and temperature dependencies; voltage and current offsets; equivalent input noise and asymmetrical slew rate. The output voltage and current limiting are taken account of, as well.

An advantage of the proposed model is that it is parameterized. The user utilizes only the data-sheet specifications. That makes the model easy for use and eliminates the calibration step. The necessary data from the tables and graphics in the specifications are described in details in the paper.

1. INTRODUCTION

Since Spice simulation is widely used for circuit analysis and system design, all major competitors in operational amplifiers market are providing their customers with Spice-based macromodels.

Two methods of OpAmp macromodeling exist: 1) reducing the complexity of the circuit and 2) the build method.

With the first method only the signal path transistors are modeled accurate and the auxiliary circuits (biasing, protection) are replaced with linear elements, such as voltage and current sources, resistors, etc. The benefit of this macromodel design approach is the reduction of the number of nodes and non-linear devices, both of which lead to a lower simulation time and required computer resources.

With the second method, the performance of the OpAmp is characterized by formal approximation of data-sheets using ideal linear elements, such as resistors, capacitors, inductors, dependent and independent sources. The advantages of this method are the computational efficiency, the simplicity and the ease of model parameter extraction.

These two methods are combined in the macromodeling technique, the popular OpAmp Spice macromodel developed by Boyle [2] being an example. This model and its successors were designed using the simplification method to design the input stage and the build method for the remainder of the OpAmp. These models suffice for many general applications. A few of the limitations are the lack of temperature performance, poor modeling of common-mode input range and offsets, the shortage of power supply rejection and noise components, etc.

In the last years the OpAmp Spice behavioral macromodel was developed, where the frequency and time characteristics are implemented using nonlinear controlled voltage and current sources [1].

The proposed OpAmp behavioral macromodel in this paper is further improved. It includes additional parameters and characteristics. The model is parameterized – the data-sheet characteristics are set as parameters.

2. DESCRIPTION OF THE ABM OPAMP MACROMODEL

The electrical diagram of the resulting OpAmp behavioral macromodel is shown in Fig.1.

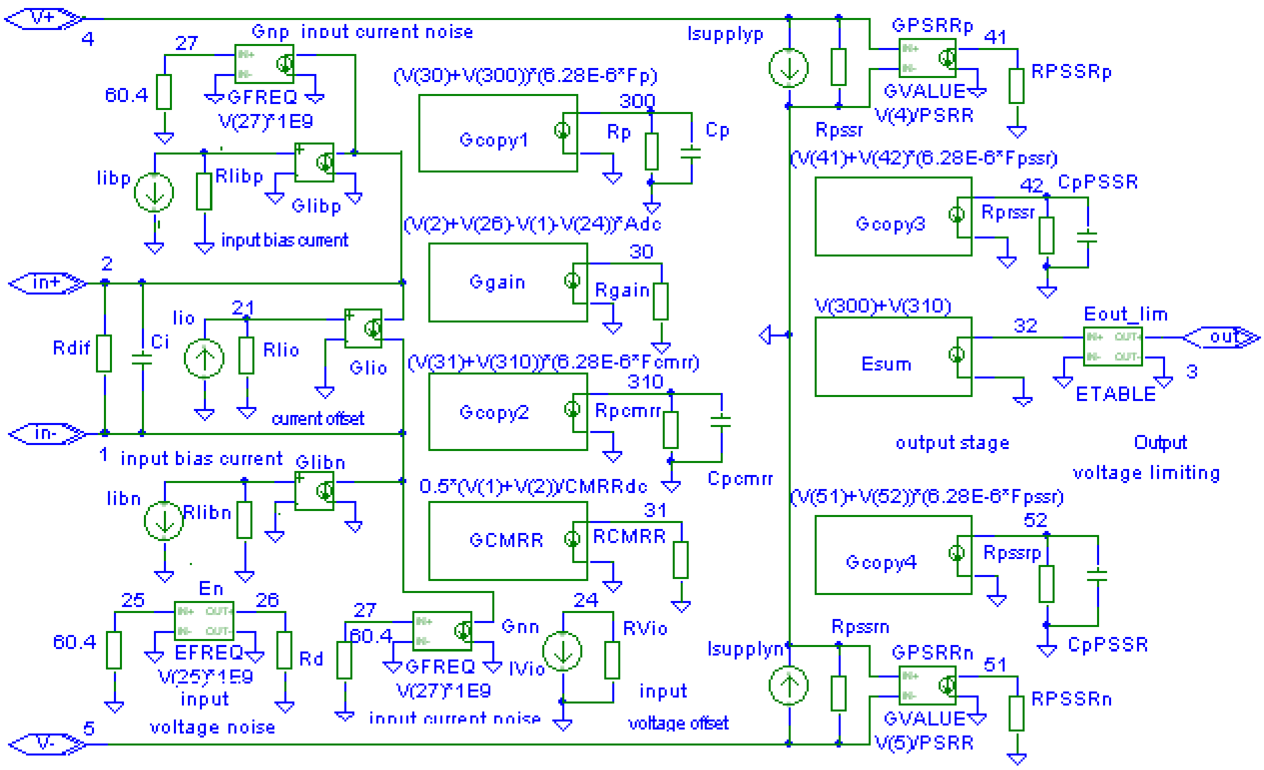

Fig. 1.

The macromodel is built-up of three blocks.

The input stage models the input impedance, the input voltage offset, the input bias and offset current and the equivalent input noise. The *I* constant current sources model the offsets: *IVio* – for the offset voltage, *Iibp* and *Iibn* – for the bias current and *Iio* – for the offset current. The values of these sources are equal to the corresponding values of offsets, specified in the data-sheets. The temperature dependence and tolerance for the Monte Carlo analysis simulate using the associated unity resistors R_{Vio}, R_{Iio}, R_{Iibp}, R_{Iibn}. Their temperature coefficients need to be specified equal to the coefficients of the corresponding voltage or current offsets. To correctly describe the temperature response, not only the value of the temperature coefficient is needed but also the shape of this response. Two types of shapes may be modeled using a resistor: linear and square. The offset tolerances can be simulated using these resistors - they have a uniform or Gaussian distribution of its value. All offset currents inject at the input by the *G* controlled sources, named *GIio*.

A goal of the proposed ABM macromodel is the modeling of the frequency dependent input noise. In the existing behavioral models the input noise is simulated by a combination of noisy diodes. In the proposed model the input voltage and current noise are modeled using *EFREQ* and *GFREQ* statements. By these operators the values of input voltage and current noise spectral density are provided for a set of frequencies. This approach is very effective especially at high frequencies and for the FET input operational amplifiers, where the noise can not be modeled accurately using diodes.

The next stage models the asymmetrical slew rate, the differential and common mode gains and power supply rejection with their temperature and frequency dependencies and tolerances. The DC differential mode gain is modeled with the *Ggain* ant its tolerance and temperature dependence is given by the *Rgain* resistor. The resulting voltage is copied by the *Gcopy1* source, that limits the output current available to charge and to discharge the capacitance from the first differential gain frequency shaping circuit, that gives also the OpAmp's dominant pole. The parameterized slew rate is realized using TABLE statement that allows modeling the slew rate with its maximum and minimum values.

The frequency dependence is simulated using *RC* elements, where for fixed *C* the value of *R* is calculated by the equation:

$$R_p = 1/\left(2\pi C_p f_p\right), \tag{1}$$

where f_p is the pole of the frequency response.

The DC common mode gain is modeled by GCMRR current source, its tolerance and temperature dependence is given by the R_{CMRR} resistor and the frequency shaping is done by *Gcopy2*, C_{pCMRR} and R_{pCMRR}.

Similarly, the two DC power supply rejections are modeled with the *GPSSRp* and *GPSSRn* sources, their tolerance and temperature variations are given by the *RPSSRp* and *RPSSRn* resistors and their frequency shaping is done by *Gcopy3*, *Gcopy4*, C_{pPSSR1}, C_{pPSSR2}, R_{pPSSRn} and R_{pPSSRp}. The *E* source provides the influence of *PSRR* over *Uio*.

The output stage models the output impedance, the voltage and current limiting. The power supply dependence of the voltage limiting and the power supply range is modeled by Eout_lim with TABLE source. The short-circuit current limiting is implemented using "If-Then-Else" current source that uses the positive and the negative limiting currents as model parameters.

The modeling of time and frequency domain characteristics is separated using individual elements with no interdependencies between parameters. The model is realized only using controlled voltage and current sources and passive elements that lead to a very low computational time and preventing convergence problems. The used resistors in the ABM model are noiseless in order to improve the accuracy of the noise analysis.

The proposed model is parameterized. The model parameters extraction is easy – the necessary data specify from tables and graphics in the specifications.

3. SIMULATION REZULTS

Figures 2, 3 and 4 illustrate some simulation results obtained with PSpice 9.2 simulator for the existing and the proposed ABM OpAmp macromodel. The new model is compared with the enhanced Boyle model.

Fig.2 and Fig.3 show the plots of the open loop voltage gain and phase response for the OpAmp OPA27. The results are summarized in Table 1.

Table 1.

parameter	Built-in Spice macromodel	Behavioral macromodel	Data-sheets
Adc	124.9 dB	123.8 dB	124 dB
f_p	3.65 Hz	4.13 Hz	4 Hz

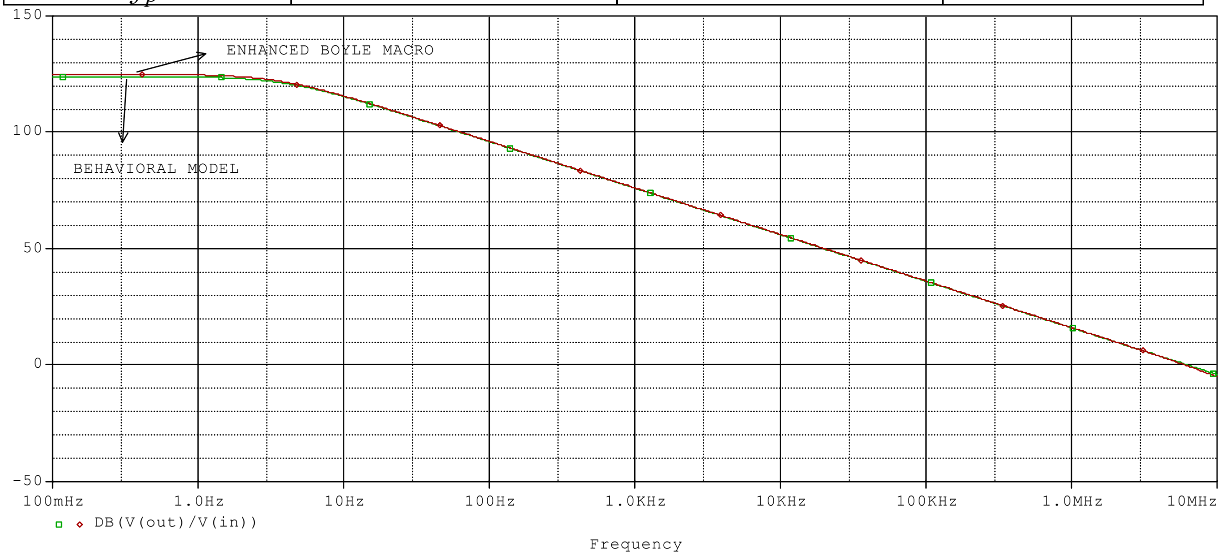

Fig. 2.

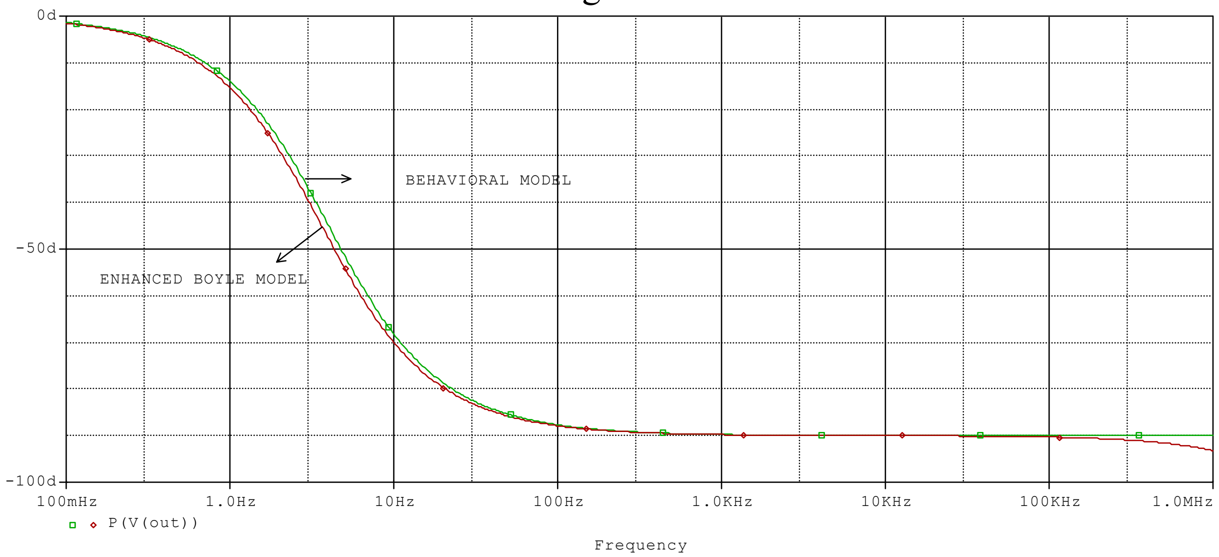

Fig. 3.

Fig.4 shows the input voltage noise spectral density vs. frequency for the OpAmp OPA2604. The proposed ABM macromodel describes very accurate the noise characteristic.

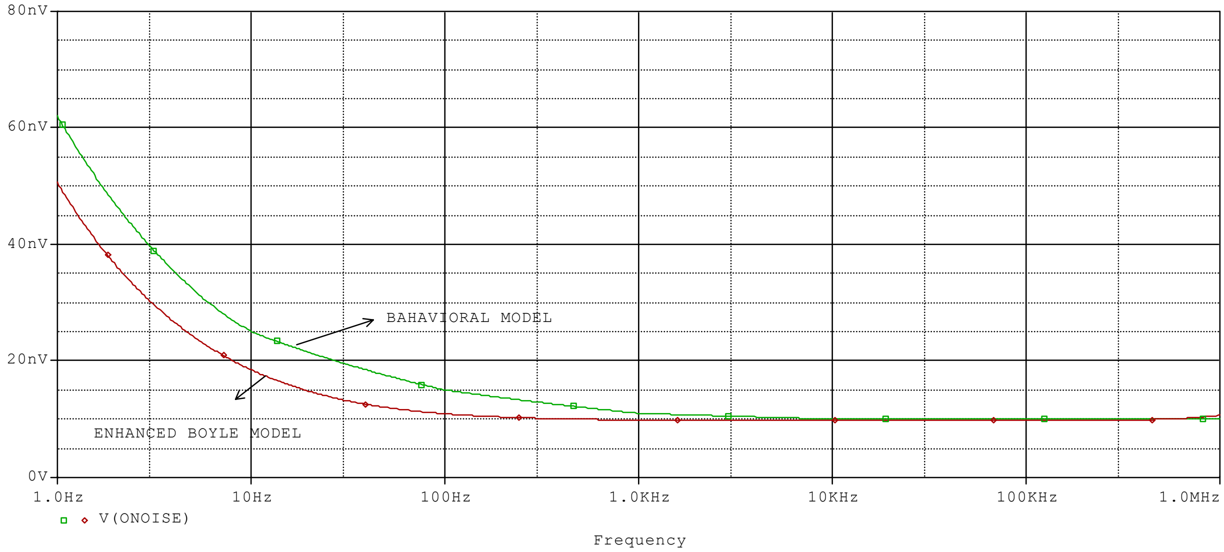

Fig. 4.

4. CONCLUSIONS

A new analog behavioral macromodel of operational amplifier is developed. An advantage of the proposed model is that it is parameterized. The user utilizes only the data-sheet specifications. The accuracy in the noise section is improved in comparison with the other known behavioral models. The input bias current and the input offset current with their temperature coefficients are described, too.

The proposed behavioral Op Amp Spice model is effective, accurate, easy for use and valid for all existing Op Amp technologies.

5. REFERENCES

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