Real Number Models for Op Amp Filters Implemented in VHDL

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1. The Real Number Model Development for the Op Amp Low-Pass Filter

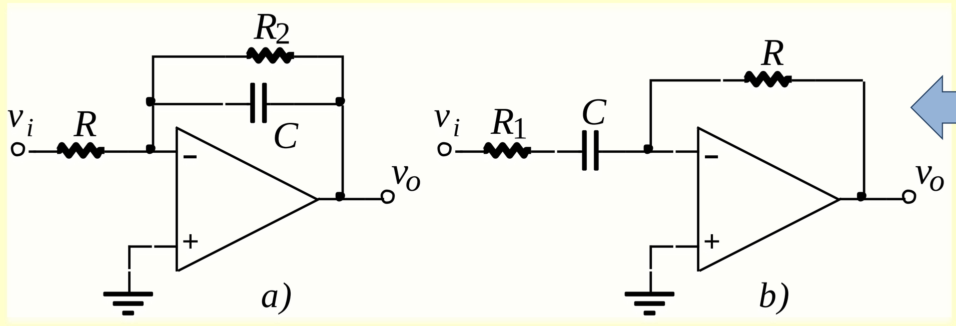
Real Number Modeling:

- Models analog block operation as discrete real data;
- It is a representation of analogue functionality in the digital world;
- Digital simulation speeds permit high volume regression tests.

This **paper presents** the functional simulation results based on an **original model** of the **analog filters with op amps**, compares the results with the pure analog SPICE simulation and analyzes the limits of the proposed model.

The **Op Amp parameters** included in the model are:

- the input offset voltage: V_{IO} – simply added to the input voltage;
- the output saturation: V_{o_H} and V_{o_L} – high and low saturation voltages;
- the slew rate limitation (max. output voltage variation with time): SR;
- the finite open-loop voltage gain at dc: a_{v0}.



The schematics of the low-pass / high-pass filters with op amps

The Op Amp slew-rate and saturation limitations algorithm.

The z-domain transfer function for the op amp low-pass filter is:

$$H(z) = \frac{V_o}{V_i} = \frac{A_{v0}}{1 + K\dfrac{1-z^{-1}}{1+z^{-1}}} = \frac{A_{v0} + A_{v0}z^{-1}}{(1+K)+(1-K)z^{-1}} = \frac{n_0 + n_1 z^{-1}}{d_0 + d_1 z^{-1}}$$

where: $n_0 = n_1 = A_{v0} = -\dfrac{R_2}{R}$, $\quad K = \dfrac{2\tau_2}{T_s} = \dfrac{2R_2C}{T_s}$,

$d_0 = 1 + K$, $d_1 = 1 - K$, T_s = sampling interval

Solved for V_o:

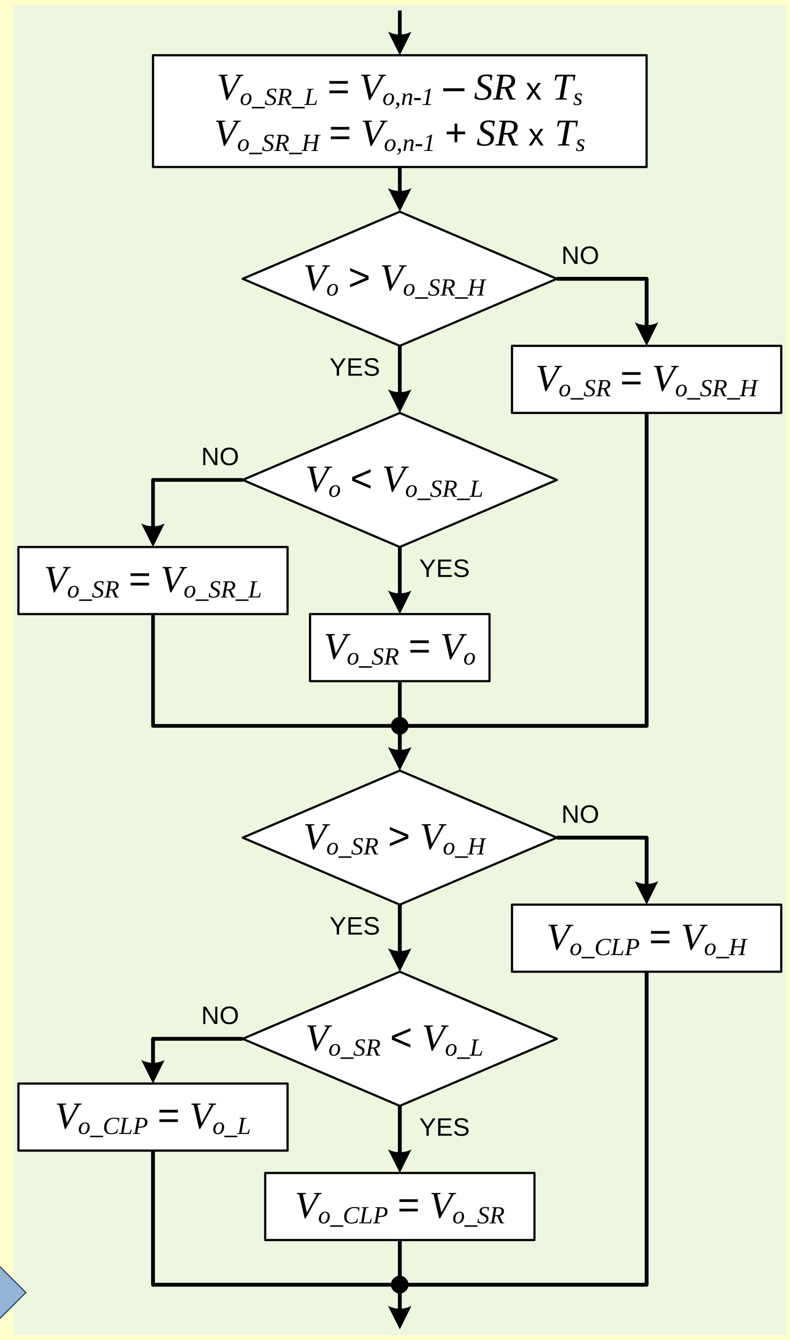
$$V_o = \frac{V_i \times (n_0 + n_1 z^{-1}) - V_o \times d_1 z^{-1}}{d_0}$$

In terms of input and delayed values of input and output:

$$V_o = \frac{V_{i,n} \times n_0 + V_{i,n-1} \times n_1 - V_{o,n-1} \times d_1}{d_0}$$

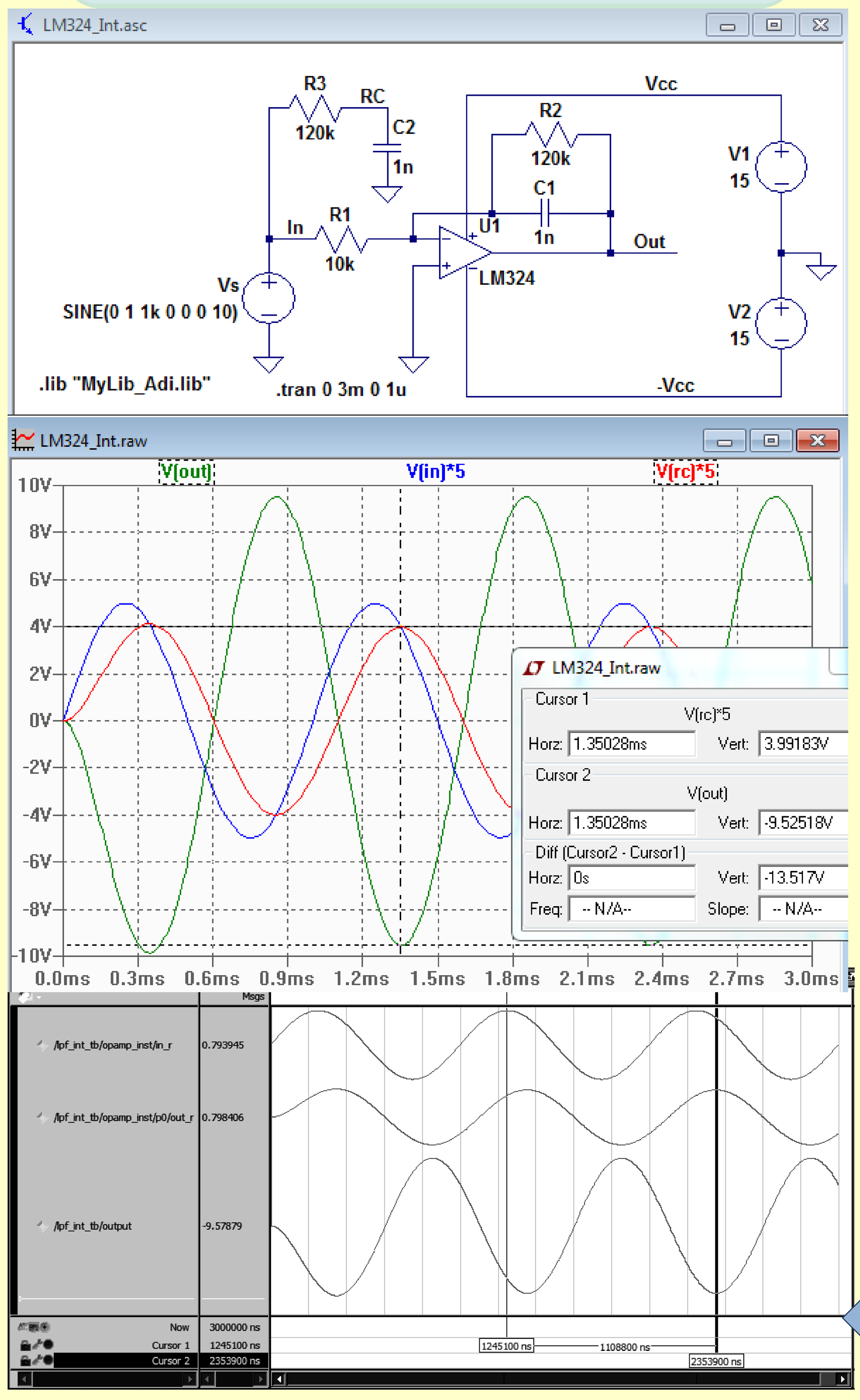
The previous formula can be used for any 1st order s-domain function transferred in z-domain with bilinear transform:

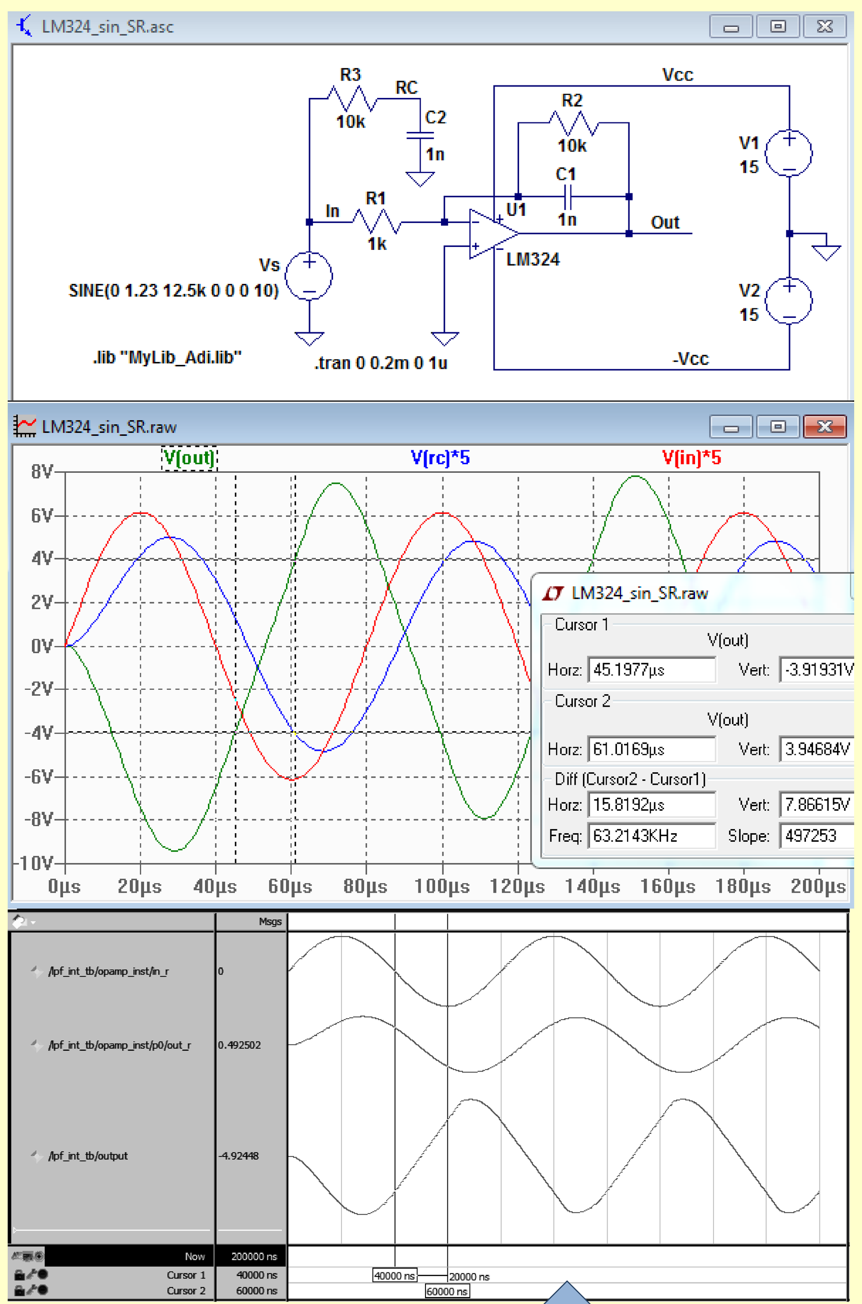
$$s = \frac{2}{T_s}\,\frac{1-z^{-1}}{1+z^{-1}}$$



2. SPICE Model versus RNM Model for the Op Amp Low-Pass Filter

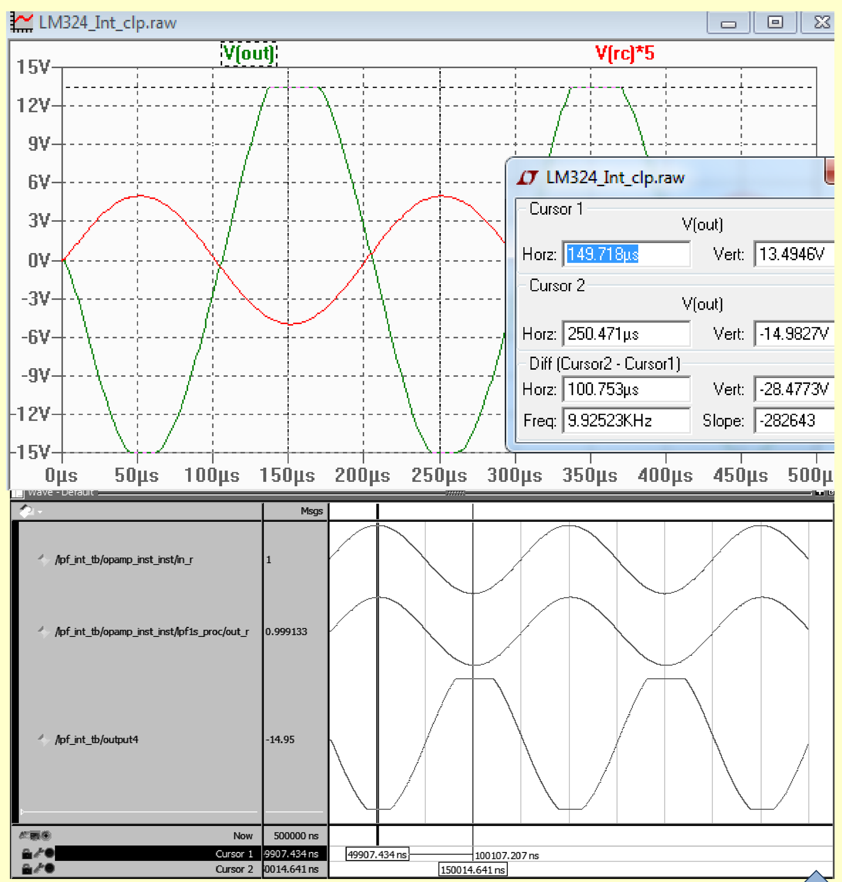
The parameters for the VHDL Op Amp model were chosen to be close to the SPICE ones.

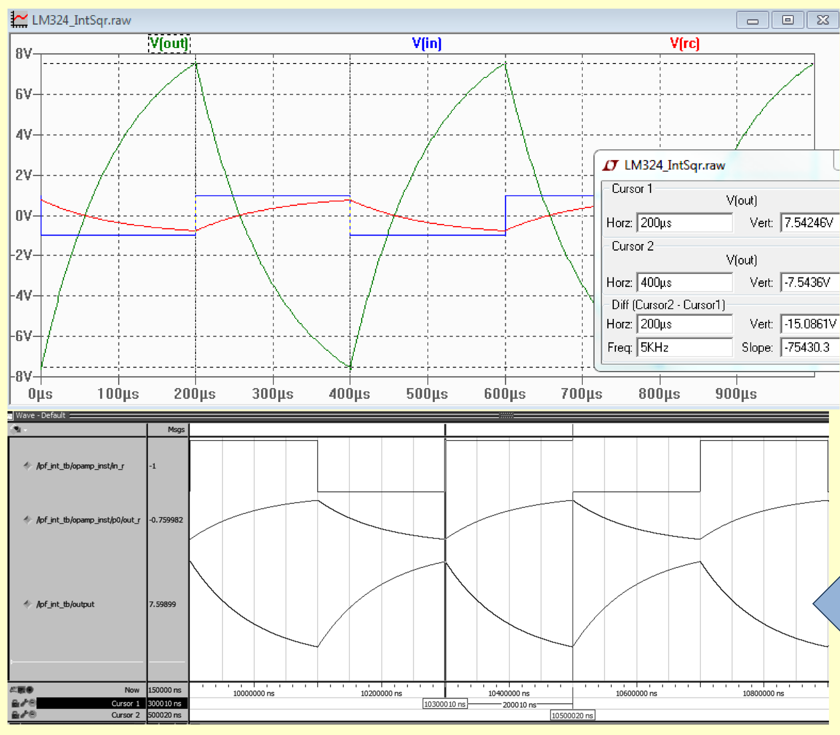


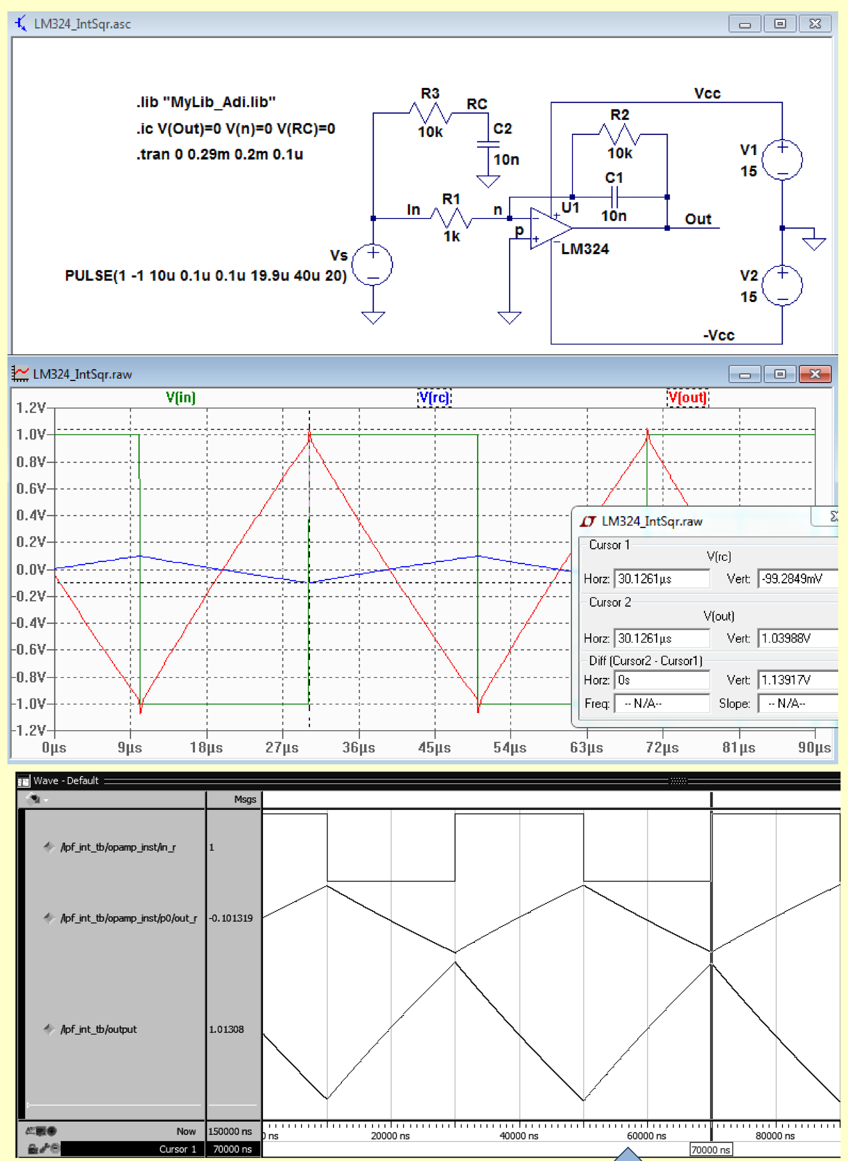


LTspice and VHDL simulations to verify the model SR limitation

LTspice and VHDL simulations results for the op amp integrator







LTspice and VHDL simulations to verify the clipping

LTspice and VHDL waveshaping circuit and simulations

LTspice and VHDL simulations for a nonlinear waveshaping

3. Conclusions

This paper describes simple real number models of op amp low-pass and high-pass filters.

The steps of op amp filters modeling presented in this paper are:

1. Derive the s-domain transfer function;
2. Use the bilinear transform to derive the z-domain function;
3. Solve the output as function of input and older values of input and output;
4. Implement the function in VHDL.

The op amp model is completed with: input offset voltage, SR limitation, open-loop voltage gain at dc and saturation voltages.

Comparison results of the simulation using SPICE and VHDL models, simulated in LTspice and ModelSim:

- The behavior of both models is similar for sine input, square input, SR and saturation limitations with a precision of the output wave global parameters better than 0.8%;
- The VHDL simulation does not contain some 2nd order effects: the glitches of fast slope variations and the smoothing of the output voltage slope variations produced by SR limitations.
- The proposed model gives a good representation of the circuit behavior and has been successfully used with digital simulators.

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