SNAP: A tool for the analysis and optimization of analogue filters

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Abstract: *The SNAP program as an effective tool supporting partial design stages of analogue filters is introduced. The symbolic and numerical analyzers of linear and linearized circuits constitute the SNAP core. This tool has been designed for supporting main design stages of both the passive and active filters effectively: a principle verification using the symbolic analysis, modeling of the influence of real parameters of active elements and parasitic reactances using the semisymbolic and numerical analyses, the possibility to work with the models of arbitrary active elements (e.g. CCII, CCIII, OTA, BOTA,..) without limitation, the sensitivity analysis and the further filter testing and optimization, the component design to reach the required filter parameters, and the export of the symbolic and numerical results to the standard universal programs for further processing.*

Introduction

The active filter design for the frequency range over 1 MHz brings a number of specific problems, which can be effectively solved by means of computer. Let us get tree typical design activities: verification of the basic circuit principle; verification of the influence of the real element parameters on the circuit function; finding the ways how to compensate these influences.

These activities automation is necessary in connection with the utilization of a wide scale of a new components (CCII, CCIII, OTA, BOTA,..), whose relevant behavioral models for the frequency range over 1 MHz are only constituted, as well as with the possibility of a filter operation in the voltage, current and a mixed modes.

The symbolic analysis is advantageous to the verification of the circuit principle. This type of analysis generates an equation of the corresponding circuit function, e.g. voltage transfer, as a function of the component parameters and the complex frequency *s*. The second recommended step is the semisymbolic analysis, whose results are numeric coefficients of the transfer function. The zeros and poles, the frequency responses, the filter reactions to the given signals in the form of equations and graphs, etc. can be obtained from the semisymbolic results.

The symbolic analysis is useful for smaller circuits, for example for the building blocks of the cascade synthesis. Its completing by the semisymbolic analysis is always advantageous. In the case of large circuits, it is better to use directly the semisymbolic approach based on the numerical algorithms. The semisymbolic analysis along with the zero/poles computation can play an important role for the investigation of the influences of real properties and parasitics on the filter behavior.

Placing the symbolic, semisymbolic and numerical algorithms to the optimization loop yields a powerful tool of the filter optimization and the real properties compensation (e.g. correction of the frequency or the impulse response).

Claims to the program tool

To realize ideas mentioned above, we need a program tool, which would enable us:

- To work with linear models of both the common and special circuit components from the resistors to the current conveyors of the all known generations and the special OpAmps. The models have to be global (i.e. working on the level of the equivalent two-ports), not on the level of the complicated SPICE models. For example, let us investigate the influence of the OpAmp cutoff frequencies on the final filter frequency response. Then we choose a OpAmp global model describing the final DC open loop gain, the first and the second cutoff frequency, and the output resistance. The simple modification and expansion of the model library belongs to the important requirements.

- To provide the symbolic analysis of required circuit functions (voltage and current gains, imittances and transimittances, all the used twoport parameters including the wave impedances, relative and absolute sensitivities of all circuit functions to the parameters of all circuit elements). For a better lucidity, it is necessary to apply some elementary simplifications of the generated symbolic expressions. In the case of the large circuits when the symbolic results are not directly exploitable and the analysis is a time-consuming, the user has to have a possibility to disable the symbolic analysis. The program core is then constituted of the semisymbolic algorithms.
- To provide the semisymbolic analysis of all the circuit functions. If the symbolic results are available, one can utilized them to substitute numerical parameters. As a further possibility (and the necessity in the case of large circuits), the symbolic results can be obtained by the numerical algorithms directly from the circuit matrix. Analyzing large circuits, it is necessary to compute coefficients of the transfer function from the zeros and poles, not conversely. In addition, the high numerical accuracy has to be reached using special polishing techniques.
- To enable the frequency analysis of all the circuit functions with the possibility to compute and plot the amplitude and phase responses, Bode plots, group delay, real and imaginary parts of any circuit function, etc. Since the zeros and poles are available, the group delay can be computed from the exact equation, not using the numerical differentiation.
- To obtain the impulse and step responses in the form of equations and plots.
- Stepping all given component parameters and investigating its influence on the filter performance.
- To define so-called algebraic circuit couplings. For instance, consider an active second-order filter. To adjust the quality factor Q with the fixed natural frequency f_0, we can change capacitances C_1 and C_2, keeping their relationship. Let us define an auxiliary variable x and two coupling conditions $C_1 = C_1\ x$ and $C_2 = C_2\ /x$. Stepping the variable x leads to the desired effect.
- To design the component parameters to fulfill required criterion. For instance, consider an active filter. Due to a OpAmp GBW, the filter cutoff-frequency is decreased comparing to the ideal case. The task is to recalculate filter resistors in such way to shift the cutoff-frequency to the original position.
- To export the analysis results to the outside environs for a following processing. We often need the graph export in the vector format to the Window Clipboard and to a file, the graph export as a table of computed points to the spreadsheets and to other graphic programs, and the export of the symbolic and semisymbolic equations to MAPLE, MathCad, MATLAB and related programs.

Based on these requirements, the SNAP system has been designed.

SNAP program

SNAP program (Symbolic Network Analysis Program) has been originally compiled for the symbolic analysis of general linear and linearized circuits. This window-based analyzer uses the symbolic algorithms by Prof. Cajka [1]. Step by step, this program has been extended to the new features mentioned above.

The input data for the analysis are read from a netlist, which is generated by the schematic editor. The netlist is of the common SPICE format. Program core is based on the algorithms of symbolic computation. Its utilization seems to be optimal while analyzing smaller circuits. User can modify the analysis method (e.g. disabling symbolic analysis and computing semisymbolic results numerically) in the program global settings.

The set of circuit elements and their models can easily be modified and extended by simply editing two text files which are necessary complements of SNAP. In this way, user can extend his analyzing potency by own models without any stint.

The matrix analysis method based on the modified nodal approach is implemented in the SNAP program. The required circuit functions are solved using the matrix subdeterminants. The method applied utilizes a special technique for economical matrix representation. To speed up the symbolic analysis, the classical algorithm of determinant expansion has been modified using the graph theory. Thanks to this approach, the implemented method is not memory- and time- expensive, and the symbolic analysis is very fast.

Illustrative example

Let us verify that the circuit in Fig. 1 [2] containing the negative current conveyor CCII- is a low-pass filter with the parameters defined in the figure description. First of all, we verify the circuit principle, avoiding any nonidealities. Then a modeling of the main real influences will be performed along with the analysis of their mechanism using the symbolic and semisymbolic results.

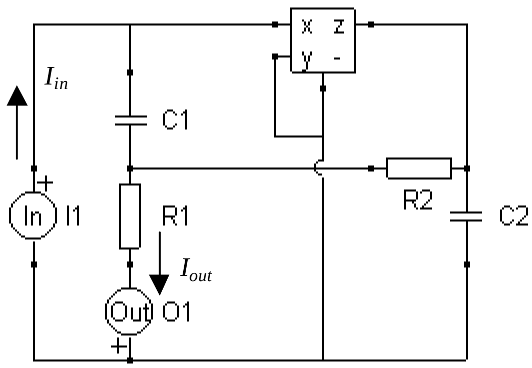

Fig. 1. *Second-order current-mode lowpass filter, f_0 = 1MHz, Q = 10; $R_1 = R_2$ = 160W, C_1 = 20nF, C_2 = 50pF.*

The input/output gates are marked by the components I (input)/O (output) in the schematic editor. The symbolic results and pole/zero analysis of the transfer function I_{out}/I_{in} by the SNAP program are summarized in Tab. 1. It is confirmed in the column "ideal" that the circuit is a second-order lowpass filter with a given transfer function. The corresponding frequency response in Fig. 2 shows the resonance ripple according to Q = 10 on the frequency f_0 = 1MHz. In the column R_0, the analysis is put more precisely considering a parasitic resistance R_0 of the X outlet of the current conveyor. As known, this resistance implicates the undesired distortion of the frequency response in the transition and stop bands. This phenomenon is confirmed in the Fig. 2. The symbolic result in Tab. 1 offers an explanation: Owing to the resistance R_0, two real zeros have appeared in the transfer function. Additionally, the original complex poles are modified. Zeros represent two additionally folds in the Bode plots on the frequencies 1,75 MHz and 18 MHz, and together with the poles they course the finite stopband attenuation $1 + R_1/R_2 + R_1/R_0$. To eliminate this phenomenon in a passive way (i.e. without the topology modification), the condition $R_1 >> R_0$ has to be fulfilled.

Analyzing the symbolic equations yields the second knowledge: Due to R_0, the absolute values of the complex poles (i.e. frequency $w_0 = 2pf_0$) are decreased in the relation to the squared root of the expression $1+R_0/R_1+R_0/R_2$. For our filter, this relation represents falling from 1 MHz to 970 kHz. However, the most important is the Q falling: In the course of a moderate decreasing of w_0, the real parts of poles were increased significantly. As a result, the quality factor is reduced from 10 to 1,42 (see Fig. 2).

The last column in the Tab. 1 shows the analysis results, taking into account not only the parasitic resistance R_0, but also the output transadmittance of the CCII. It should be noted that this influence is negligible comparing to the R_0 effect which is dominant.

Given example indicates that this topology is not suited for the filters with the higher quality factors in the frequency range near 1 MHz.

I_{out}/I_{in}	***ideal***	***R*₀ = 5W**	***R*₀ = 5W, *R*ₜ=3MW, *C*ₜ = 4.5pF**
symbol	$\frac{1}{s^2R_1R_2C_1C_2+sC_2(R_1+R_2)+1}$	$\frac{s^2R_0R_2C_1C_2+sR_0C_1+1}{s^2C_1C_2(R_0R_2+R_0R_1+R_1R_2)+s(R_1C_2+R_2C_2+R_0C_1)+1}$	*complicated and not relevant*
zeros	-	*-1.09612E7* *-1.14039E8*	*-1.10675E7* *-1.03617E8*
poles	*-3.12500E5±j6.24218E6*	*-2.13235E6±j5.67607E6*	*-1.98363E6* *±j5.45874E6*

Tab. 1. *Analysis results for a various models of the CCII: ideal – ideal CCII-;* ***R_0*** *– resistance of the X outlet; R_t, C_t –components of the parasitic transadmittance of the Z outlet.*

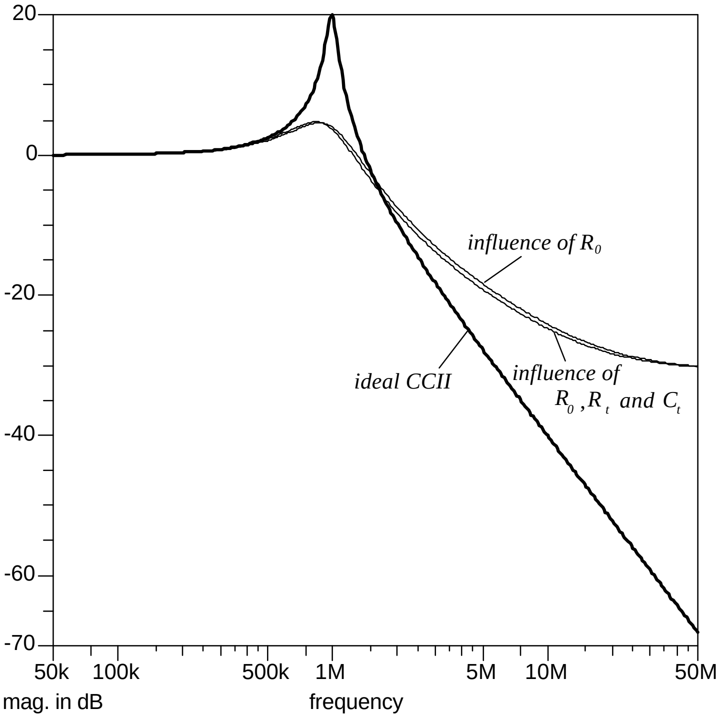

Fig. 2. *SNAP outputs: frequency responses for various models of CCII-.*

Conclusion

Using the described SNAP system, we can model the dominant influences of the real properties of active filters, study the causes of the nonideal behavior, and - if possible and suitable - propose their compensation and perform the filter optimization according to the specified target functions.

More SNAP functions including the working with the Dependence Editor and in the optimization mode are described in [3].

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