OPTIMIZATION OF ANALOGUE FILTERS FOR TELECOMMUNICATIONS USING SYMBOLIC AND SEMISYMBOLIC APPROACH

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ABSTRACT

The utilization of symbolic and semisymbolic algorithms as the effective tools supporting partial design stages of analogue filters is introduced. The corresponding software 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 component parameters 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.

1. 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).

2. CLAIMS TO THE OPTIMIZATION TOOLS

To realize ideas mentioned above, we need a program tools, 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, immittances and transimmittances, 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

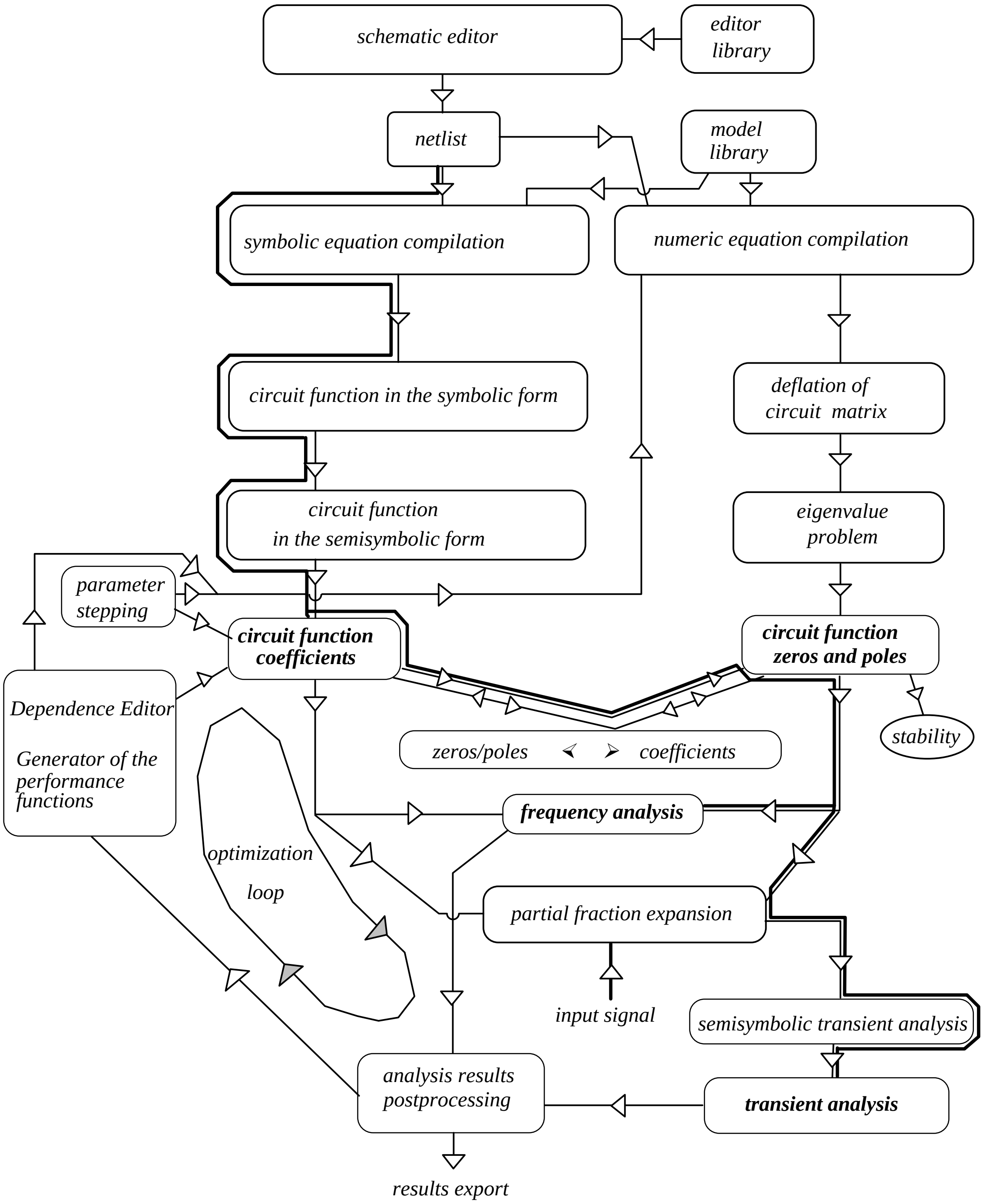

Fig. 1. Simplified block diagram of the analysis and optimization tool.

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.

3. PROGRAM TOOL

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], [2]. Step by step, this program has been extended to the new features mentioned above.

The simplified program block diagram is in Fig. 1. 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. In Fig. 1, a heavy line marks the default analysis sequence. This sequence seems to be optimal while analyzing smaller circuits. User can modify the analysis parameters (e.g. disable 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.

4. UTILIZATION EXAMPLE

Let us perform preliminary synthesis of an active cascade filter. For instance, we can use the NAF program [3]. The last second-order Sallen-Key block is in Fig. 2 with the parameters f_0 = 9.675kHz and Q = 8.818. Program has determined R and C elements on the assumption of ideal OpAmp. We are warned by the program that utilization of OpAmp with the GBW<39MHz will lead to the nonidealities in the frequency response. Particularly,

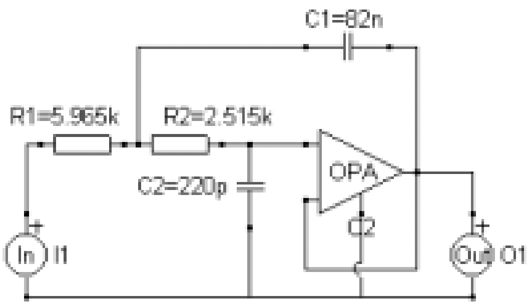

Fig. 2. Example of optimized 2nd order lowpass Sallen-Key filter.

lowering f_0 is expected. Nevertheless, we decide to use type 1458 with GBW = 1MHz. For this case, program performs so-called passive correction which consists in recomputation R1 and R2 to R1'= 5.253kΩ a R2'= 2.214kΩ with the aim to compensate this phenomenon as much as possible.

The following symbolic and semisymbolic analysis yields coefficients of the voltage transfer function both as symbols and numbers:

```
______________symbolic__________________
1
--------------------------
1
+s*( R2*C2 +R1*C2 )
+s^(2)*( R1*R2*C1*C2 )
```

$$K_V = \frac{1}{1 + sC_2(R_1 + R_2) + s^2 R_1 R_2 C_1 C_2}$$

```
____________semisymbolic_______________
Multip. Coefficient =  3.69500499137902E+009
 1.00000000000000E+000
---------------------------------
3.69500499137902E+009
+6.89340131191167E+003 * s
+1E+000 * s^(2)
```

$$K_V = 3{,}695x10^9 x \frac{1}{3{,}695x10^9 + 6{,}8934x10^3 s + s^2}$$

```
_______________zeros__________________
none
_______________poles__________________
-3.44670065595835E+003 + j  6.06887571628159E+004
-3.44670065595835E+003 - j  6.06887571628159E+004
```

From the symbolic expression, it is easy to derive well-known design rules for f_0 and Q

$$f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}, Q = \sqrt{\frac{C_1}{C_2}} \frac{\sqrt{R_1 R_2}}{R_1 + R_2}$$

which give directions how to adjust f_0 and Q independently. These rules can be utilized later for a final filter optimization by the Dependence Editor.

By using the ideal filter coefficients, the ideal frequency response can be plotted. We can copy it to so-called waveform clipboard for following needs (see Fig. 3).

The analogous analysis is then performed for the filter with one-pole OpAmp model. The model parameters will correspond to the OpAmp 1458: open-loop gain A = 200000, GBW = 1MHz, output resistance Ro = 75Ω:

```
_____________symbolic_________________
A*GBW
+s*( C1*Ro*GBW )
+s^(2)*( C1*A*Ro +R2*C1*C2*Ro*GBW )
+s^(3)*( R2*C1*C2*A*Ro )
-------------------------------------
A*GBW +GBW
+s*( C1*Ro*GBW +R1*C2*GBW +A +R2*C2*A*GBW
+R2*C2*GBW +R1*C2*A*GBW +R1*C1*GBW )
+s^(2)*( C1*A*Ro +R1*C2*A +R1*C1*A
+R1*C1*C2*GBW*Ro +R2*C1*C2*GBW*Ro +R2*C2*A
+R1*R2*C1*C2*A*GBW +R1*R2*C1*C2*GBW )
+s^(3)*( R1*C1*C2*A*Ro +R2*C1*C2*A*Ro
+R1*R2*C1*C2*A )
____________semisymbolic_______________
Multip. Coefficient =  1.20619837287116E-002
 1.84647776313295E+018
 5.67791912163383E+007 * s
 1.80736920735972E+006 * s^(2)
1.00000000000000E+000 * s^(3)
```

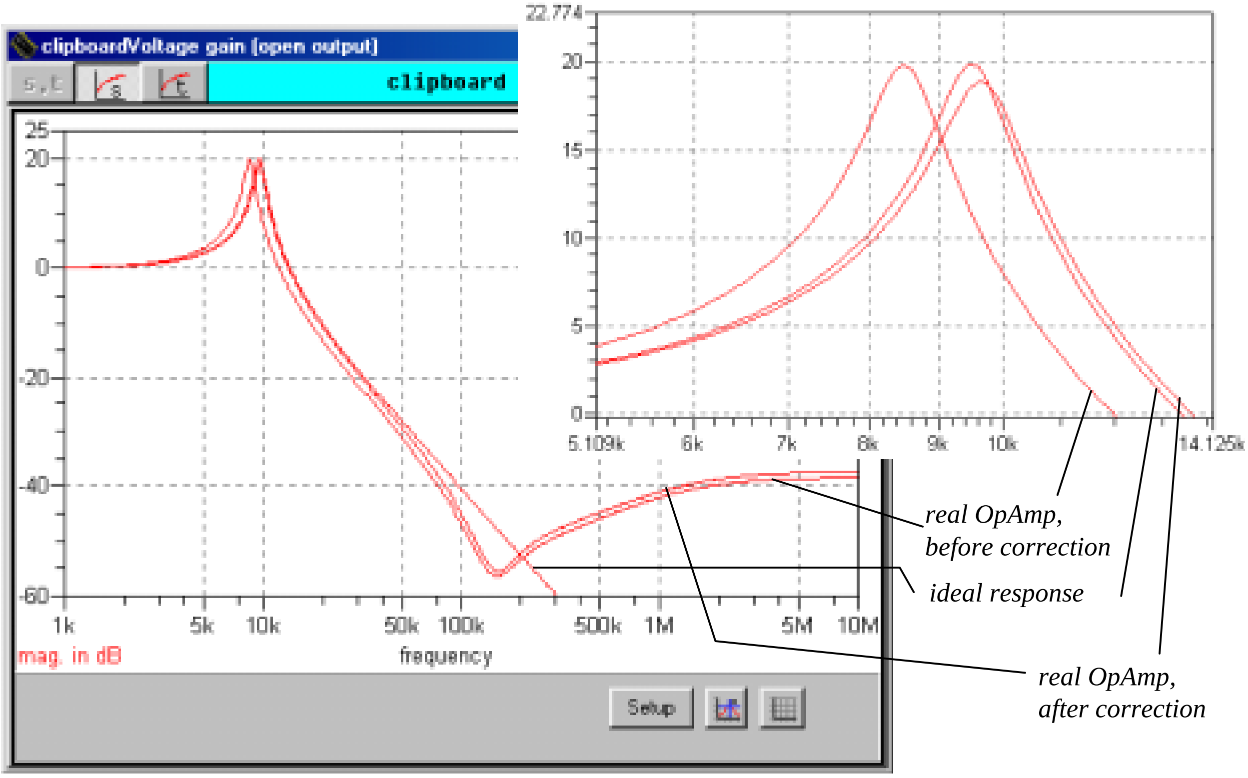

Fig. 3. Illustration of the first stage of the optimization process.

2.22722960952613E+016
4.51510787315717E+010 * s
7.78992421724248E+006 * s^(2)
1.00000000000000E+000 * s^(3)
_______________zeros_________________
-2.19173106573066E+006
1.92180929185471E+005 + j 8.97519412114406E+005
1.92180929185471E+005 - j 8.97519412114406E+005
_______________poles_________________
-7.78449162516349E+006
-2.71629603949472E+003 + j 5.34203418706269E+004
-2.71629603949472E+003 - j 5.34203418706269E+004

It should be noted that due to real OpAmp one real pole has appeared, existing complex poles are now modified, and some parasitic zeros have grown. Fig. 3 shows the influence on the frequency response. The gain maximum is moved toward the lower frequencies, and the well-known unsuitable attenuation drop-off appears in the stopband. From the symbolic result (as the relation between the coefficients corresponding the highest powers of *s*-operator), we can derive formula of the final stopband attenuation:

$$K_\infty = 1 + \frac{R_1}{R_2} + \frac{R_1}{R_o} \doteq 83 \triangleq 38 dB \cdot$$

Obviously, this attenuation can be partially increased by increasing the impedance level, especially by the choice $R_1 >> R_o$.
Finally, we can modify R1 and R2 to R1'and R2'and to verify the efficiency of the passive correction. As shown in Fig. 3, this correction is not perfect and it leads to a mild drop-off *Q*. The final optimization will be performed in the optimization loop by the utilization of Dependence Editor and Generator of Performance functions (see Fig. 2).

5. CONCLUSION

Main concept of proposed software tool for filter analysis and optimization is described. The tool core is constituted by algorithms of symbolic and semisymbolic analysis. It enables modeling dominant influences of the real properties of active filters, to study the causes of nonideal behavior, and - if possible and suitable – to propose their compensation and to perform filter optimization according to specified target functions.

6. REFERENCES

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