APPLICATION OF POSTPROCESSING FOR OBJECTIVE FUNCTION FORMULATION IN THE STATISTICAL OPTIMIZATION USING PSPICE

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An approach is proposed in the paper to automated statistical circuit optimization using the general-purpose circuit analysis program Cadence PSpice. The selection of the optimal variant is based on postprocessing in the graphical amalyzer Probe. The objective functions are formulated and calculated using corresponding macrodefinitions.They are defined as corresponding modules for optimization, introduced in Probe. The optimal values of the circuit parameters are also obtained in the graphical analyzer Probe using predefined macros using simulation results in the frequency or in the time domain. The statistical PSpice optimization allows the application of the rich possibilities of Probe graphical analyzer for construction complex objective functions, multi-extremal, as well as non-differetiable functions. Examples are presented to illustrate the proposed approach.

Keywords: Statistical optimization, *PSpice* simulation, Objective functions

1. INTRODUCTION

The increased complexity of electronic systems being designed today and the constantly growing number of components complicate significantly their design and optimization. Analog circuits require application of powerful CAD systems with extended possibilities for adequate modeling, simulation in different modes of operation, design tolerance assessment, optimization, as well as postprocessing of the obtained simulation results. Different approaches are developed to computer-aided analog circuit optimization. The computer-aided circuit design needs to be managed with appropriate optimization algorithms and accurate statistical description of design models in order to reach the design specifications. Complexity of analysis increases when tolerances and statistically distributed parameters are considered. A number of optimization methods are tested and compared with benchmark examples in [1] and several methods are also combined. Based on benchmark examples it is concluded, that almost any optimization method can be successfully used on any problem. The SPICE program is used by several authors solving various optimization problems. In [2] an approach is proposed for integration generic optimization algorithms into SPICE. The implemented program has proven to be an extremely efficient optimization tool for an experienced circuit designer. Evolutionary computing and algorithms are optimization tools that are utilized for various areas of analog electronic circuits design, diagnosis, yield and cost optimization [3]. Optimization tools are incorporated in standard circuit simulators. *Cadence PSpice Optimizer* offers four search engines to optimize the design: LSQ, modified LSQ, random, and discrete. *ASCO* [4] aims to bring circuit optimization capabilities to existing SPICE simulators. This tool uses a hybrid optimization strategy with a high-performance differential evolution (DE) global optimization algorithm. There exists a support of *ASCO* for the general-purpose circuit programs *Eldo*, *HSPICE*, *LTspice/SwitcherCAD* III, *Spectre* and *Qucs*. Recently, the *Monte Carlo* method has been successfully applied to the optimization procedure and has proven useful for global optimization, as well as in the case of non-differentiable and multi-extremal objective functions.

An approach is proposed in the present paper to automated statistical circuit optimization using the general-purpose circuit analysis program *Cadence PSpice*. It is based on postprocessing in the graphical amalyzer *Probe*. The objective functions are formulated and calculated using corresponding macrodefinitions. The optimal values of the circuit parameters are also obtained in *Probe*. The statistical *PSpice* optimization allows the application of the rich possibilities of *Probe* graphical analyzer for construction complex objective functions, multi-extremal, as well as non-differetiable functions. Examples are presented to illustrate the proposed approach.

2. OBJECTIVE FUNCTION FORMULATION

The intervals for the circuit parameter optimization are defined by the TOLERANCE attribute. Uniform distribution is used for generation of the variants. The minimization of the objective function is performed in the graphical analyzer *Probe*. The case of non-differentiable objective function is considered with the optimization of the low-pass filter shown in Fig. 1.

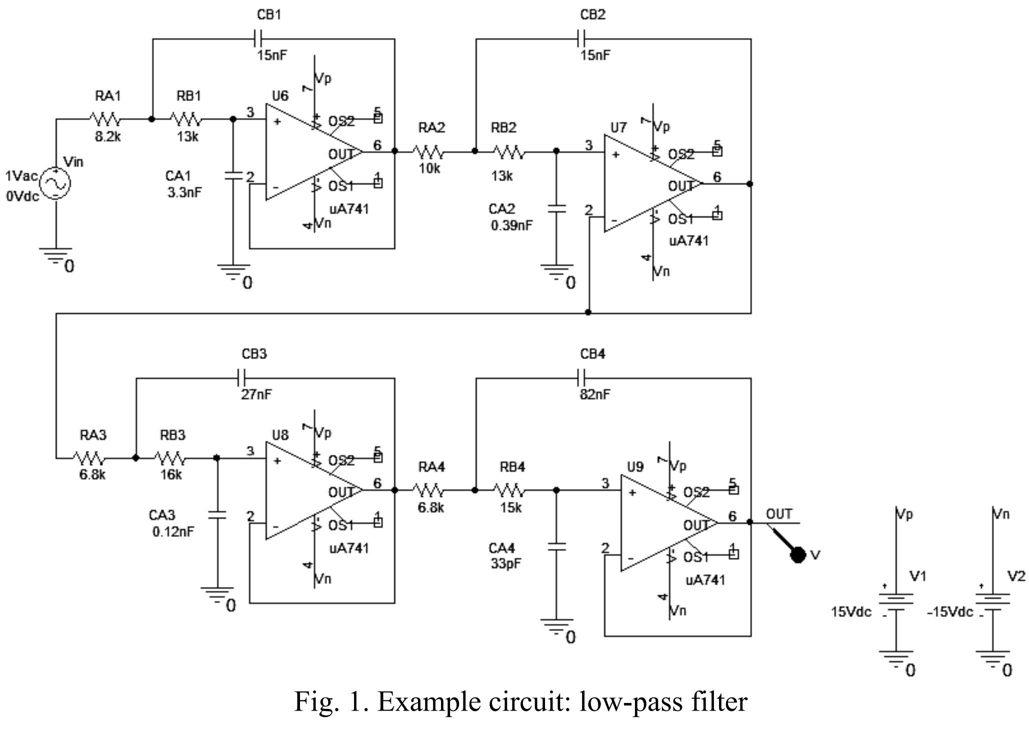

Fig. 1. Example circuit: low-pass filter

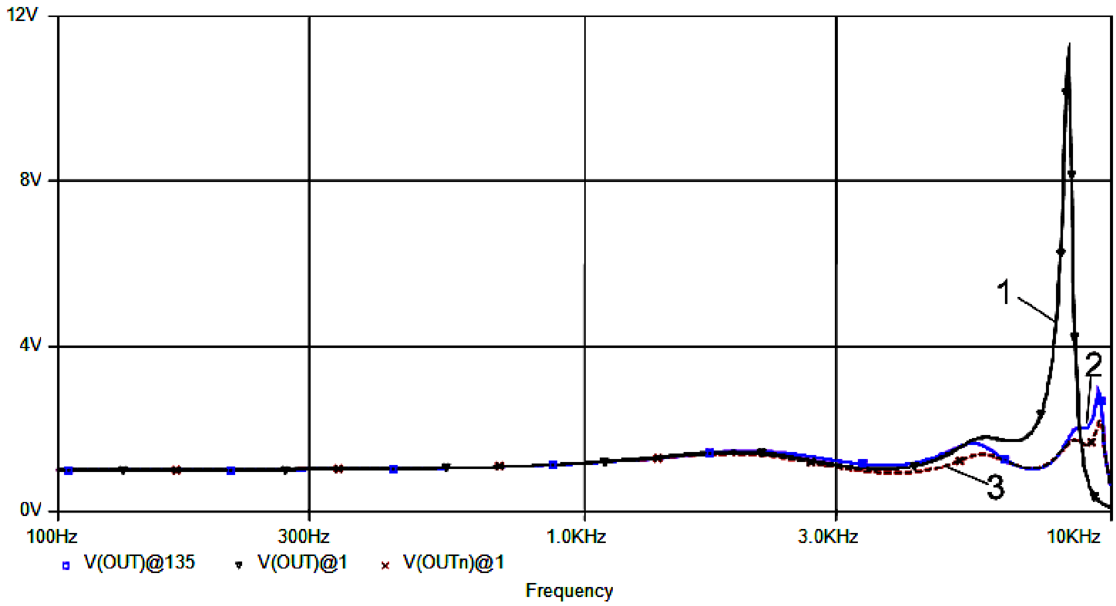

Fig. 2. Frequency response of the circuit in Fig. 1: initial (1), optimized (2) and target curve (3)

The frequency response of the circuit is shown in Fig. 2. The target curve 3 (dashed line) corresponds to the case of ideal OpAmps. The characteristic 1 is the response with real OpAmps. The objective function is constructed in order to fit the real characteristic 1 to the desired curve 3.

The following characteristics are calculated in *Probe*:

1. Relative distance $V_{\max r}$ of the maximal magnitude $V_{OUT\max}$ to the target value $V_{OUT\,n\max}$:

$$V_{\max r} = \frac{abs\left(\max\left(V_{OUT}\right) - \max\left(V_{OUTn}\right)\right)}{\max\left(V_{OUTn}\right)} \tag{1}$$

1. Relative distance $V_{\min r}$ of the minimal magnitude $V_{OUT\min}$ to the target value $V_{OUT\,n\min}$:

$$V_{\min r} = \frac{abs\left(\min\left(V_{OUT}\right) - \min\left(V_{OUTn}\right)\right)}{\min\left(V_{OUTn}\right)} \tag{2}$$

2. Relative distance V_{LFr} of V_{OUT} to $V_{OUT\,n}$ at lower frequencies

The parameter ena_{LF} is introduced in order to select and control the value of V_{OUT} at lower frequencies:

$$ena_{LF} = \begin{cases} 1 & f \le f_1 \\ 0 & f > f_1 \end{cases} \tag{3}$$

The output voltage at lower frequencies ($f < f_1$) V_{LF} is obtained in the form:

$$V_{LF} = ena_{LF}.V_{OUT} \tag{4}$$

As a result:

$$V_{LFr} = \frac{abs\left(\max\left(V_{OUT,LF}\right) - \max\left(V_{OUTn,LF}\right)\right)}{\max\left(V_{OUTn,LF}\right)} \quad (5)$$

The objective function ε_r is:

$$\varepsilon_r = w_1 V_{\max r} + w_2 V_{\min r} + w_3 V_{LFr}, \quad (6)$$

where w_1, w_2 and w_3 are weighting coefficients

The macrodefinitions in *Probe*, which realize the equations (1) – (6), have the form:

```
Vmaxr=max(abs(max(Vm(OUT))- max(Vm(OUTn)))/max(Vm(OUTn)))
ena_LF=(sgn(10-frequency)+1)/2
V_LFr =abs(max(ena_LF*Vm(OUT))-
max(ena_LF*Vm(OUTn)))/max(ena_LF*Vm(OUTn))
Vminr= max(abs(min(Vm(OUT))-min(Vm(OUTn)))/min(Vm(OUTn)))
EPSr =V_LFr+Vmaxr+10*Vminr
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The optimized parameter values are obtained from the dependencies:

$$R = \frac{V_R}{I_R}\ ; \quad C = \frac{I_C}{2\pi f V_C}\ ; \ L = \frac{V_L}{2\pi f I_L} \quad (1)$$

They are calculated using predefined macros:

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V_R(RR) = M(V(RR:1,RR:2)/I(RR))
V_C(CC) = M(I(CC)/V(CC:1,CC:2))/(2*pi*FREQUENCY)
V_L(LL) = M(V(LL:1,LL:2)/I(LL))/(2*pi*FREQUENCY)
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Monte Carlo simulation is used as an optimization tool. Uniform distribution 10% is defined for *R* and *C* elements. The optimized characteristic is shown in Fig. 2 (curve 2). The parameter values after optimization are presented in Table 1. Assigning standard values (1% for resistors and 5% for capacitors), the frequency response of the circuit with real OpAmps is obtained (curve 2st in Fig. 3). The characteristic 1 corresponds to the circuit with initial values, 2 – to the circuit with optimized parameter values (Table 1), and characteristic 2st – optimized circuit with standard parameter values.

Table 1

element	value	element	value	element	Value	Element	Value
R_{A1}	8.51 kΩ	R_{A3}	6.41 kΩ	C_{A1}	3.03 nF	C_{A3}	0.122 nF
R_{B1}	13.7 kΩ	R_{B3}	16.0 kΩ	C_{B1}	15.3nF	C_{B3}	28.0 nF
R_{A2}	9.08 kΩ	R_{A4}	6.25 kΩ	C_{A2}	0.41 nF	C_{A4}	29.8 pF
R_{B2}	13.0 kΩ	R_{B4}	14.2 kΩ	C_{B2}	13.6 nF	C_{B4}	75.2 nF

The case of differentiable objective function is considered with the optimization of the band-pass filter shown in Fig. 4. Uniform distribution is 10% is defined for *R* and *C* elements.

The objective function ε_r is obtained as a RMS value:

$$\varepsilon_r = \sqrt{\sum_i \left(V_{OUTi} - V_{OUTni}\right)^2}$$

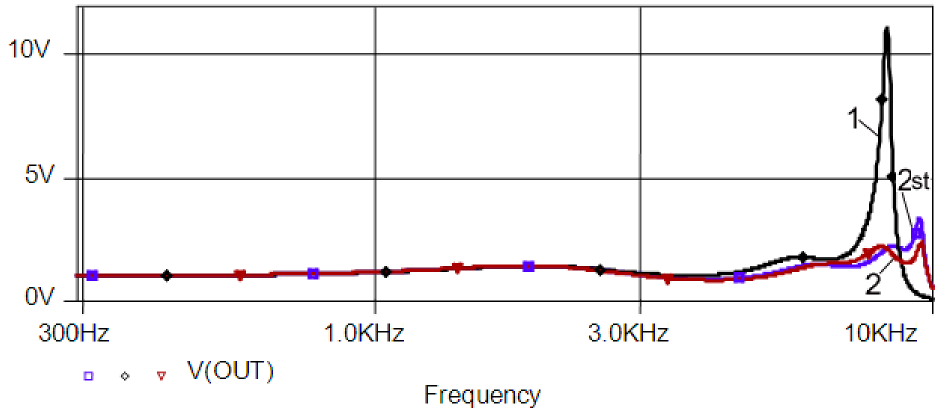

Fig. 3. Frequency response of the circuit: initial (1), optimized (2) and optimized with standard parameter values (2st)

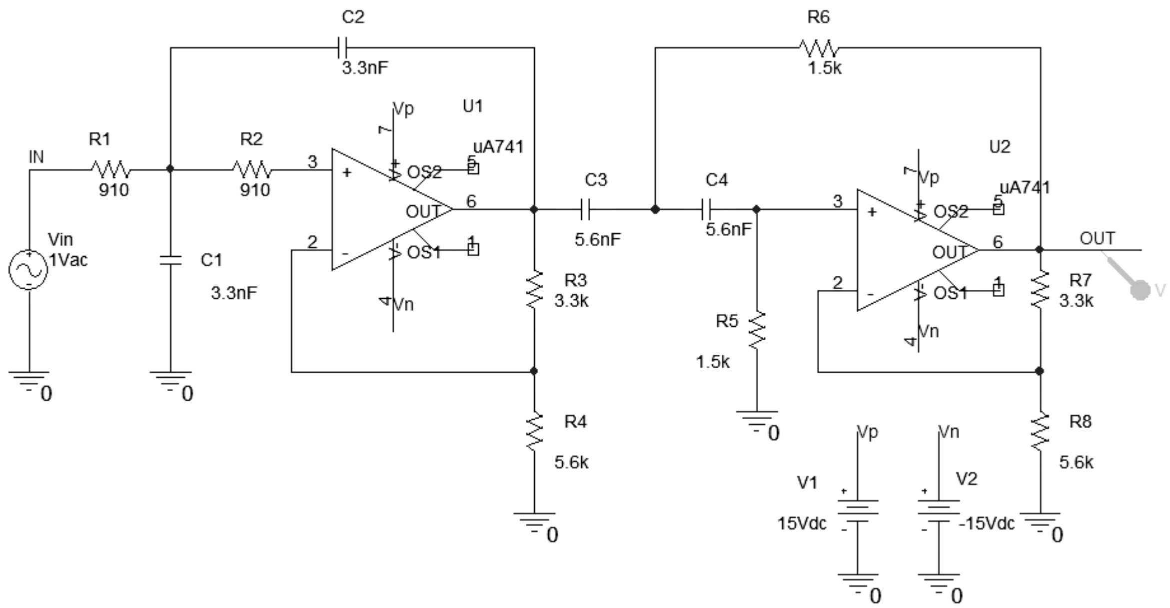

Fig. 4. Example circuit: band-pass filter

It is realized by the following macro in *Probe*:

EPSr= rms(Vm(OUT)-Vm(OUTn))

The optimization results for the frequency response are presented in Fig. 5. The characteristic 1 is the response with initial parameter values and real OpAmps, and the characteristic 3 is the target response. The characteristic 2 corresponds to the optimized circuit with real OpAmps. Assigning standard values (1% for resistors and 5% for capacitors), the frequency response 2st of the circuit with real OpAmps is obtained. The optimized parameter values are shown in Table 2.

The application of *Monte Carlo* simulation as an optimization tool allows the optimiztion of differenciable, non-differenciable and multi-extremal objective functions. Using the extended possibilities for macrodefinition in *Probe*, various objective functions can be formulated by the user.

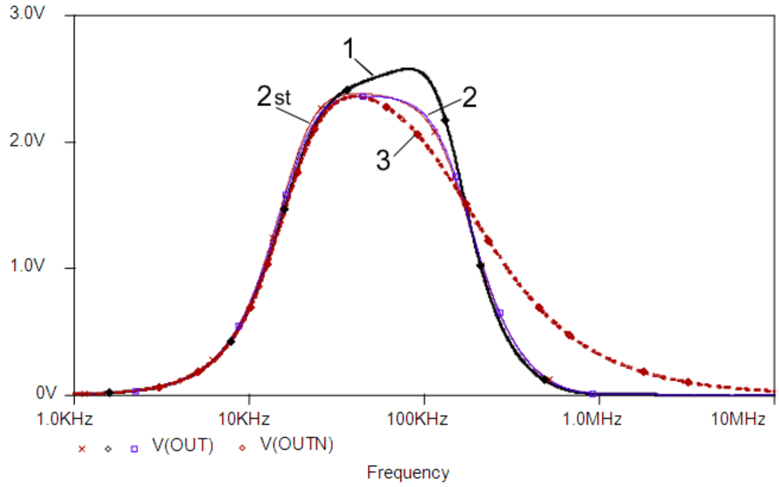

Fig. 5. Frequency response of the circuit: initial (1), optimized (2), optimized with standard parameter values (2st) and target curve (3)

Table 2

element	value	element	value	element	value	element	Value
R_1	827 Ω	R_4	5.65 kΩ	R_7	3.55 kΩ	C_2	3.0 nF
R_2	833 Ω	R_5	1.54 kΩ	R_8	6.1 kΩ	C_3	5.27 nF
R_3	3.09 kΩ	R_6	1.49 kΩ	C_1	3.25 nF	C_4	6.05 nF

3. CONCLUSION

A computer-aided optimization approach has been developed in the paper using possibilities of the statistical simulation using general-purpose *PSpice*-like circuit analysis programs. The objective function formulation is performed in the graphical analyzer *Probe* using corresponding macrodefinitions. The optimal values of the parameter values of the circuit elements are also calculated in *Probe*. The application of *Monte Carlo* simulation as an optimization tool allows the optimization of differenciable, non-differenciable and multi-extremal objective functions.

4. ACKNOWLEDGEMENT

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5. REFERENCES

[1] Janez PUHAN, Tadej TUMA, Iztok FAJFAR, *Optimisation Methods in SPICE, a Comparison*, Proceedings of the ECCTD'99, vol. 1, 1999, pp. 1279-1282.

[2] Janez Puhan, Iztok Fajfar, Tadej Tuma and Arpad Bűrmen, Integration of Generic Optimisation Algorithms in SPICE, Electrotechnical Review, Ljubljana, Slovenija, 68(1), 2001,

[3] P. JANTOS_ and J. RUTKOWSKI, Evolutionary methods to analogue electronic circuits yield optimisation, Buletin of the polish academy of sciences, Technical sciences, Vol. 56, No. 1, 2008.

[4] ASCO - [4] ASCO - *A SPICE Circuit Optimizer*, asco.sourceforge.net/doc/asco.html