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VRATISLAV **MICHAL**, KAREL **HAJEK**, JIRI **SEDLACEK**
UNIVERSITY OF DEFENCY, BRNO UNIVERSITY OF TECHNOLOGY, CZECH REPUBLIC

MODERN OPERATIONAL AMPLIFIERS AND THEIR DEGENERACY EFFECTS ON ACTIVE FILTER PERFORMANCE

Abstract: In the last year in area of active filter design many new modern active elements as OTA , VCF amplifiers and operational amplifiers with large GBW parameter are used. Their performance enables to produce active filters working at higher frequency ranges. In the process of filter design and optimization very important step is a CAD modelling. Here a major role plays requirement of sufficient accuracy by active element modelling. How we can see from demonstrative example of active filter Sallen-Key with operational amplifier from Fig.1, modelled filter response namely at higher frequency is determined by accuracy of modelled operational amplifier.

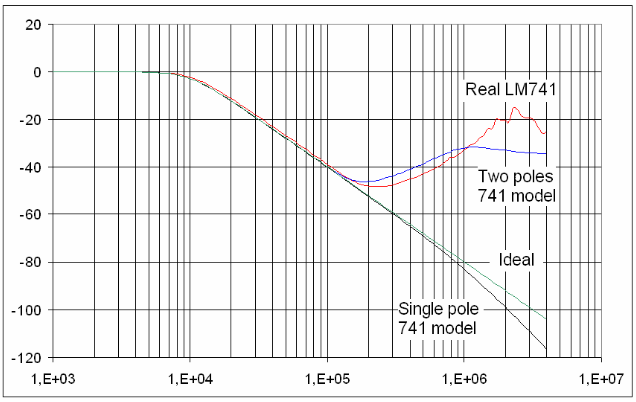

Fig. 1 An example of model accuracy influence by FDNR filter response modeling

However by usage of well known and usually presented linearized models of corresponding type of operational amplifier which are to disposal in software to network analysis /2/ designed practical filter realizations exhibit significant difference between modelled and resulting measured filter responses [1].

These imperfections which are caused predominantly by real active elements performance declare that accuracy of presented models of active elements (due to many parasitic elements which evidently are not included in reduced models) is not sufficient to required accuracy of modelling.

Therefore our interest in area of filter design and optimization was concentrated on work leading to improving of active element modelling. A new method which will lead to deriver the more accuracy of active element modelling was successfully verified and will be here described in case of classical operational amplifier.

From the well known open loop AC characteristic of operational amplifier (OpAmp) can be determined most important parameters of OpAmp working in linear area. These parameters are presented as 1st and 2nd pole and DC gain. The first pole is usually in order of 5-100Hz, band – width is defined most often as GBW (Gain band witdh product) in order of 1MHz up to units of GHz. The second pole (by unity gain stable amplifier) has to be bigger than GBW. This is indispensable to get the satisfactory gain and phase margin. Moreover in the linearized model is also important the output resistance. The example of linearized two-pole OpAmp model used in Tina [2] software is shown at Fig.2.

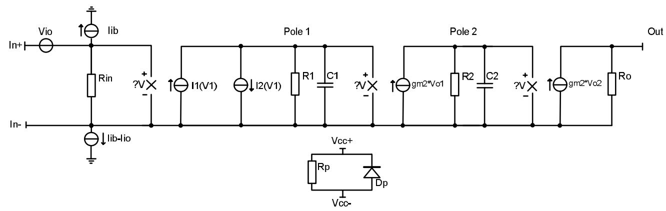

Figure 2 – Linearized two pole OpAmp model

But how declare many in practise measured filter responses, above presented linearized model is not sufficient to filter modelling namely by higher frequencies. Here must be evidently taken in to account also further parasitic parameters of the real operational amplifier. These parasitic parameters are very difficult to determine exactly. A direct measuring of the AC open-loop characteristic of OpAmp in range which is 3-10 times larger then GBW is impossible due the required extreme dynamic range (going up to 200dB).

The differences between measured real responses of designed frequency filters and non - corresponding simulated results are mostly evident in lower frequency area and are easy measurable in the dynamic range lower than 60dB. It means that the further unknown parasitic parameters of the operational amplifier are hidden (for example as further transfers zeros or poles) in the final characteristic of the frequency filter.

A new method to determining the real Op-Amps linearized parameters

As was mentioned above, the response of the real frequency filter network can be used to determine of the OpAmp linearized parameters.

To describe a new method to parameter determining here the 2nd order of lossy FNDR [3], from Fig.3 with one active element – (VCV1) which is OpAmp or others active elements modelling - will be used.

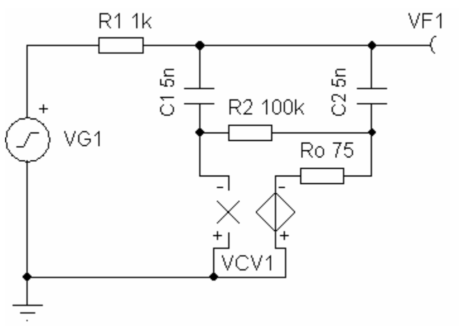

Figure 3 – 2nd order FNDR low pass circuit used for model parameters identification

First step is to use the simulated characteristic to determine the whole transfer function. For the transfer function identification, the LMS [4] method should be use. The LMS method realize the operation

$$\mathbf{P_{(i)}=(\Phi^T\Phi)^{-1}} \qquad (1)$$

Where Φ is a matrix of measured parameters and P(i) matrix of searched parameters.
For assuring of the convergence, the order of matrix and thereby the order of searched transfer function has to be checked manually.

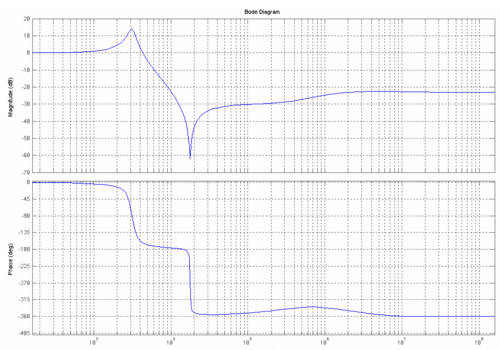

Figure 1 – Identified characteristic of FNDR low pass circuit (figure 2)

The identification process applied to the simulated AC response of circuit (Figure 2) with two poles model was be realized in Matlab environment and give the result (2). (page 4 of the article)
This transfer function is in accordance with simulated results (figure 3)
When the identification is done, the analysis of circuits (figure 2) has to bee done too. The general transfer function of circuit is shown at (3), Where Fop is a general transfer of active block and the components are the components corresponding with Fig.2

When supposing the two pole OpAmp model, the searched transfer function should bee written as (4). T
Where the A...D are the searched parameters. By substitution of (4) to the transfer function (3) with the elements values from figure 3 should be obtained the final transfer function (4)
It should be written with collected coefficients (5)
The correspondence of orders nominator and denominator coefficients of (5) with (6) show the proper order of model (4) selection. If the equality is not obtained, the order of searched model has to be changed.
The searched coefficients and equivalent output resistance value should be obtained by solving the system of nonlinear equations (7). Which compare the transfer function coefficients of general transfer (2) and (6). The results coefficients are (8). What determine to the identified transfer function (for inverted input):

$$F_{op(s)} = \frac{-3.6724\cdot 10^{11}}{0.0009304\cdot s^2 + 58457.589\cdot s + 7.6733\cdot 10^6}$$

and output resistance 75Ω (8). The simulated characteristic of identified OpAmp transfer function is shown at figure (4)

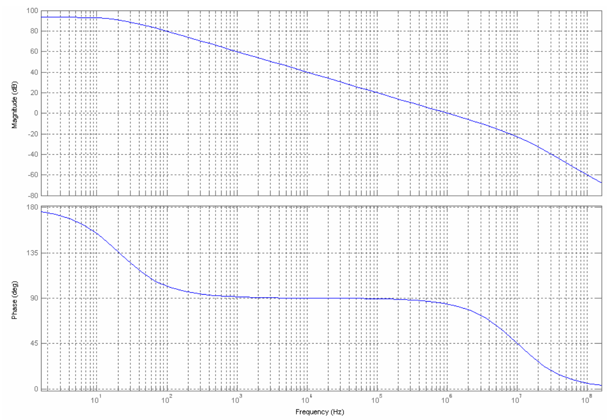

Figure 2 – Simulated characteristic of identified transfer of OpAmp

DC gain error

The information about the transfer is contained in the frequency response of the simulated filter. The DC gain of used model was 120dB. By mathematical analysis of the sensitivities, we should to find out the very low sensitivity of G_0 (DC gain) to the real performance of the filter. Contrary the GBW has important sensitivities. Therefore the error of DC gain identification has occurred. It means that the 1st pole was placed higher at the cost of decrease of DC gain. This error should be repared manually in the transfer function, but his influence to the final circuit behaviour is not significant.
For the frequencies higher than the 1st pole frequency, the identified characteristic corresponds with insignificant error with used model of OpAmp.

$$F_{(s)ident} = \frac{0.06977s^4 + 4.57\cdot 10^6 s^3 + 1.171\cdot 10^{13} s^2 + 2.492\cdot 10^{16} s + 1.469\cdot 10^{23}}{s^4 + 6.302\cdot 10^7 s^3 + 3.792\cdot 10^{14} s^2 + 1.494\cdot 10^{18} s + 1.469\cdot 10^{23}} \quad (2)$$

$$F_{LP} = \frac{-C_1C_2R_2R_O s^2 + \left(-C_1R_O - C_2R_O - C_2R_2\right)\cdot s + F_{OP} - 1}{\left(-R_1 + R_1F_{OP} - R_O\right)\cdot C_1C_2R_2 s^2 + \left(R_1C_2F_{OP} + R_1C_1F_{OP} - R_1C_2 - R_1C_1 - C_1R_O - C_2R_O - C_2R_2\right)\cdot s + F_{OP} - 1} \quad (3)$$

$$F_{op(s)} = \frac{D}{C\cdot s^2 + B\cdot s + A} \quad (4)$$

$$F(s,F_{OP}) = \frac{\dfrac{D}{Cs^2+Bs+A} - 1 + (-1.0\cdot 10^{-8}R_O - 0.00050)\cdot s - 2.500\cdot 10^{-12}R_O s^2}{\dfrac{D}{Cs^2+Bs+A} - 1 + \left(\dfrac{0.0000100D}{Cs^2+Bs+A} - 0.000510 - 1.0\cdot 10^{-8}R_O\right)\cdot s + 2.500\cdot 10^{-12}\left(-1000 + \dfrac{1000D}{Cs^2+Bs+A} - R_O\right)\cdot s^2}$$

(5)

$$\begin{aligned}&(R_O s^4 C + (2.0000\cdot 10^8 C + R_O B + 4000R_O C)\cdot s^3 + (2.0000\cdot 10^8 B + 4.0000\cdot 10^{11} C + R_O A + 4000R_O B)\cdot s^2 \\ &+ (2.0000\cdot 10^8 A + 4.0000\cdot 10^{11} B + 4000R_O A)\cdot s + 4.0000\cdot 10^{11} A - 4.000\cdot 10^{11} D/((1000C + R_O C)\cdot s^4 + \\ &(4000R_O C + 1000B + R_O B + 2.040\cdot 10^8 C)\cdot s^3 + (4.0000\cdot 10^{11} C + 4000R_O B + 1000A + 2.040\cdot 10^8 B + R_O A \\ &- 1000D)\cdot s^2 + (4.0000\cdot 10^{11} B - 4.0000\cdot 10^6 D + 4000R_O A + 2.040\cdot 10^8 A)\cdot s + 4.00\cdot 10^{11} A - 4.000\cdot 10^{11} D)\end{aligned} \quad (6)$$

$$\begin{aligned}&R_0\cdot C = 0.06977 \\ &2.00\cdot 10^8\cdot C + R_0\cdot B + 4000\cdot R_0\cdot C = 4.57\cdot 10^6 \\ &2.00\cdot 10^8\cdot B + 4.000\cdot 10^{11}\cdot C + R_0\cdot A + 4000\cdot R_0\cdot B = 1.171\cdot 10^{13} \\ &2.00\cdot 10^8\cdot A + 4.00\cdot 10^{11}\cdot B + 4000\cdot R_0\cdot A = 2.492\cdot 10^{16} \\ &4.000\cdot 10^{11}\cdot A - 4.000\cdot 10^{11}\cdot D = 1.469\cdot 10^{23}\end{aligned} \quad (7)$$

$$\left[A = 7.673313\cdot 10^6, B = 58457.5893, C = 0.000930411, D = -3.67242367\cdot 10^{11}, R_O = 74.988359\Omega\right] \quad (8)$$

Conclusion

This identification method will be used to identify the parameters of real operational amplifier as well as the OTA or VCF amplifiers. The correct model parameters in the design software should improve the final circuit's properties by optimizing of the characteristics in the stop band.

The next study will be directed to the influence of the passive components to the identification process as well as the parasitic components present in the physical realization.

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Prof.Ing. Karel Hajek, MILITARY ACADEMY Brno,
Kounicova 65, 623 00 Brno, Czech Republic
Tel. (+420) 79344 2550 Fax (+420) 79344 2550
E-mail: karelhajek@unob.cz

Ing.Vratislav Michal
FACULTY OF TECHNOLOGY,
Kolejni 4, 612 00 Brno, Czech Republic
Tel. (+420) 732166550 Fax (+330) 625717035
E-mail: vratislav.michal@gmail.com

Doc.Ing.Jiri Sedlacek,CSc.,
FACULTY OF TECHNOLOGY,
Kolejni 4, 612 00 Brno, Czech Republic
Tel. (+420) 541149520 Fax (+420) 541149512
E-mail: sedlacj@feec.vutbr.cz