SYNTHESIS OF ELECTRONICALLY RECONFIGURABLE 3RD-ORDER FLF-OS FILTER IN SINGLE-ENDED AND FULLY-DIFERENTIAL DESIGN

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Abstract: This paper deals with a proposal of 3rd-order single-ended and fully-differential frequency filters based on the follow-the-leader-feedback topology with the output summation (FLF-OS) working in the current mode. The main feature of both of these filtering structures is an ability of the electronic reconfiguration of their transfer functions. Active elements used for the filter design are implemented by transconductance amplifiers, current amplifiers and current followers. Simulation results of available transfer functions, their tunability and comparison of both circuits are presented.

Keywords: frequency filter, electronic reconfiguration, single-ended filter, fully-differential filter

1 INTRODUCTION

The electronical reconfiguration allows a synthesis of the multifunctional reconnection-less SISO circuits. Active elements with electronically controllable parametrs, which allow a reconfiguration of the transfer function, are necessary parts of this type of active filters. Elimination of undesirable frequency components and distortions in the processed signal (switching distortion) and quick response are main advantages of this realization. [1][2] One of the many topologies which is suitable for synthesis of the high order filters is the follow-the-leader-feedback topology (FLF). It is one of the general multi-loop-structure (MLS) and it is well known for its easy modular synthesis. However, there is a problem when the processed signal is differential (for example differential amplifiers or differential AD converters). It is necessary to use the fully-differential filters in the mentioned applications. High common mode rejection ratio and dynamic range are advantages of fully-differential realizations. [3]

2 SYNTHESIS OF THE SINGLE-ENDED FILTER

There are two main types of FLF topology: with input distribution into nodes of the cascade and with output summation. [4] I chose realization of the FLF filter with output summation (FLF-OS). There is essential advantage due to the current mode realization – summation of the output current is realized only by the node. Unfortunately, a higher number of output pins of the active elements is needed to collect current for feedback, next block of the cascade and output independently. [5]

I determined a form of the denominator of the general transfer function (1) from Figure 1a) with help of SNAP software. Coefficients b for polynom I determined with help of program NAF. Parameters of filter zone tolerance are: characteristics frequency $f_0 = 100$ kHz, maximal band-pass attenuation $K_{\max} = -3$ dB, band-stop frequency $f_{\text{att}} = 1$ MHz, band-stop attenuation $K_{\min} = -57$ dB and Butterworth approximation. Coefficients b are given in (2).

$$D(s) = s^3 + s^2 \frac{g_{m1}}{C_1} + s \frac{g_{m1} g_{m2}}{C_1 C_2} + \frac{g_{m1} g_{m2} g_{m3}}{C_1 C_2 C_3} = s^3 b_3 + s^2 b_2 + s b_1 + b_0 \tag{1}$$

$$b_0 = 2.4846 \cdot 10^{17} \quad b_1 = 7.9128 \cdot 10^{11} \quad b_2 = 1.2600 \cdot 10^6 \quad b_3 = 1 \tag{2}$$

The designed FLF structure consists of three lossless integrator OTA-C (1st-order) with transfer $T_{\mathrm{i}} = \frac{1}{s}$. Therefore, only all-pole filters can be realized. All-pole filters has a constant in the numerator and polynom in the denominator of the transfer function (without zeros), so the band-reject function is not available. Nominal value of all capacitors was chosen (with respect to the magnitude of the parasitic impedance) $C = C_1 = C_2 = C_3 = 1$ nF.

3 TRANSFORMATION INTO FULLY-DIFFERENTIAL STRUCTURE

The easiest way how create a fully-differential structure is a transformation which consists in mirroring of the single-ended realization. After this transformation, active elements have twice the number of outputs and same transconductance g_{m} (Figure 1b). [3] Due to on-chip implementation each floating capacitor was replaced by a pair of the grounded capacitors (Figure 1b).

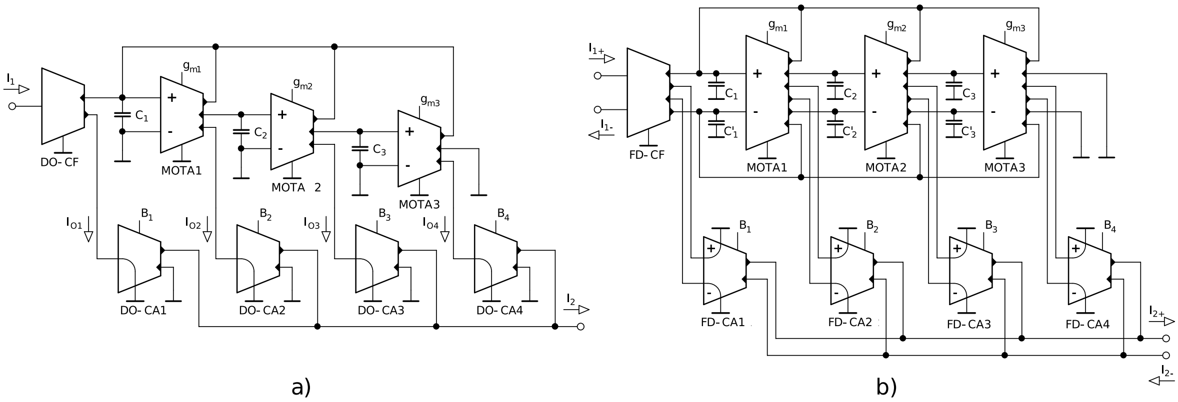

Figure 1: Designed FLF-OS 3rd-order filter in a) single-ended, b) fully-differential form

Multiple output operational transconductance amplifiers (MOTA), adjustable current amplifiers (ACA) and differential adjustable current amplifiers (FD-CA) were used in both filters. Electronic controllability of their parametrs (transconductances $g_{\mathrm{m1}} - g_{\mathrm{m3}}$ of MOTA and current gains $B_1 - B_4$ of ACA) is essential feature for implementation into the tunable filters. [1][2]

Both realizations are reciprocal, thus their transfer functions are identical. Tunability of characteristic frequency is possible by changing the transconductances of all MOTA elements simultaneously (must be in proportion). Control of the transfer function is realized by current gains $B_1 - B_4$, whereas for F-D version current gains are halved. The proposed 3rd-order S-E and F-D filter offers low-pass (LP), high-pass (HP), two asymmetric band-pass filters (BP) and 2nd-order symmetric band-pass.

Table 1: Available transfer functions and their controllability (for F-D realization in bracket)

filter	transfer function	B_1	B_2	B_3	B_4
LP 3rd-order	$K_{\mathrm{I(LP)}} = (g_{\mathrm{m1}} g_{\mathrm{m2}} g_{\mathrm{m3}})/D$	0	0	0	1 (0.5)
HP 3rd-order	$K_{\mathrm{I(HP)}} = (\mathbf{s}^3[C_1 C_2 C_3])/D$	1 (0.5)	1 (0.5)	1 (0.5)	1 (0.5)
BP 3rd-order A	$K_{\mathrm{I(BP-A)}} = (\mathbf{s}^2[g_{\mathrm{m1}} C_2 C_3])/D$	0	1 (0.5)	0	0
BP 3rd-order B	$K_{\mathrm{I(BP-B)}} = (\mathbf{s}[g_{\mathrm{m1}} g_{\mathrm{m2}} C_3])/D$	0	0	1 (0.5)	0
BP 2nd-order	$K_{\mathrm{I(BP)}} = (\mathbf{s}^2[g_{\mathrm{m1}} C_2 C_3] + \mathbf{s}[g_{\mathrm{m1}} g_{\mathrm{m2}} C_3])/D$	0	1 (0.5)	1 (0.5)	0

4 SIMULATIONS

Designed filters were simulated in OrCAD Pspice. Transistor models of transconductor (MOTA), current follower (CF) and current amplifier (ACA) in CMOS TSMC 0.18 μm technology were used.

Transconductances of appropriate MOTA ($g_{m1} = 1.26$ mS, $g_{m2} = 628$ µS and $g_{m3} = 314$ µS), which are identical for both of this circuits, I calculated from denominator coefficients by expressing from (1). In default configuration, the characteristic frequency is $f_0 = 100$ kHz and quality factor $Q = 0.92$.

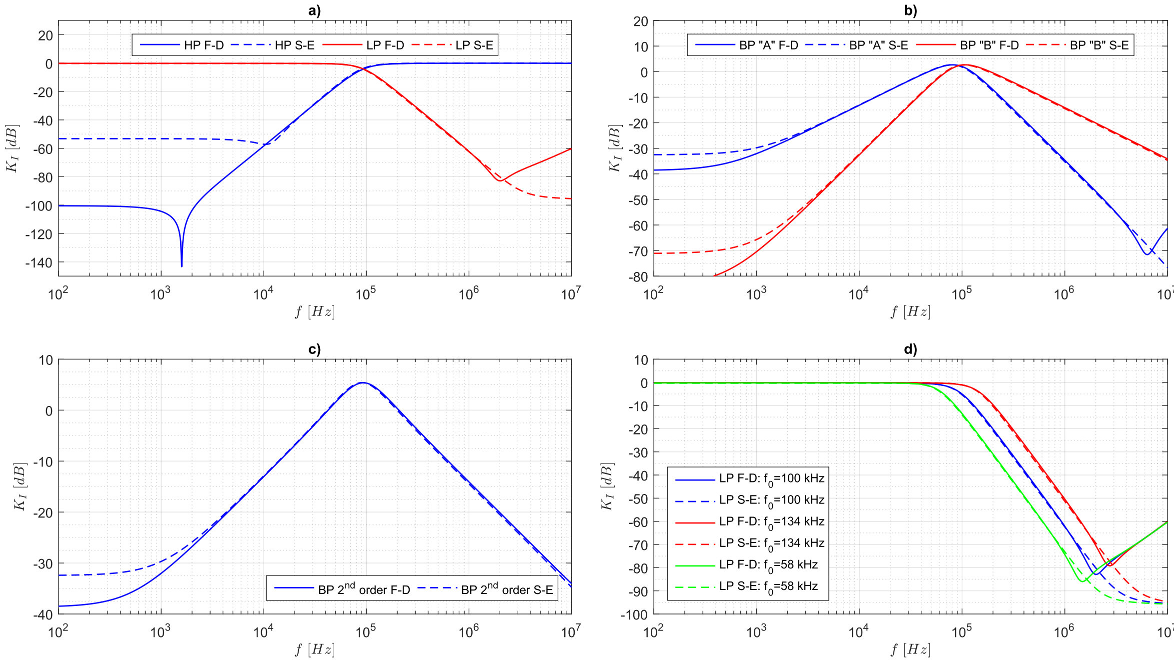

Figure 2: Module characteristics of availbale transfer functions FLF filter

5 CONCLUSION

In this paper, the electronically reconfigurable multifunctional 3rd-order FLF filter in sigle-ended and fully-differential form was proposed. Control of characteristics frequency is possible by changing the transconductances of all MOTA elements simultaneously. The proposed SISO filters have electronically controllable transfer function. It is clear, that fully-differential filter has better attenuation in band-stop area. Both circuits are suitable for on-chip implementation.

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