PSEUDO-DIFFERENTIAL HIGH-ORDER FREQUENCY FILTER

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Abstract: This article describes a pseudo-differential third-order frequency filter operating in voltage mode, using four differential difference current conveyors (*DDCCs*), and six passive elements. The circuit has a high input impedance, low active and passive sensitivity and high common-mode rejection ratio (*CMRR*). The proposed structure is able to realize one type of frequency responses low pass. Non-ideal analysis has been performed by considering the real parasitic parameters of the active elements. Optimization was made with a view to greatly influence low pass filter attenuation.

Keywords: Pseudo-differential filter, frequency filter, single-ended filter, high-order, conveyor, common-mode rejection ratio, non-ideal analysis.

1 INTRODUCTION

Frequency filters are widely used in the vast majority of electrical equipments Since the design of function blocks currently emphasizes low voltage and power, there is a growing interest in designing pseudo-differential frequency filters, which show a large percentage of common-mode rejection ratio (CMRR) and low signal distortion. In this paper, a new third-order operating in voltage-mode pseudo-differential filter using four active elements (DDCCs) is presented. Together with the active elements only six passive elements, each of them grounded, are used. Non-ideal analysis has been performed by considering the real parasitic parameters of the active elements. Optimization was made with a view to greatly influencing low pass filter attenuation.

2 PSEUDO-DIFFERENTIAL FREQUENCY FILTERS

As is evident from the mathematical description (1) of fully-differential structures shown in Fig.1a) for analysis are used only the input and output signals. Hence, it is generally possible to design differential system using input and outputs signals, where the internal structure is non-differential. Such structures called as pseudo-differential filters shown in Fig. 1b) according to [1], these filters assume differential input and output but the inner structure is rather single-ended, still provide high suppression of the common-mode signal and have lower harmonic distortions compared to single-ended structures but are less complicated compared to fully-differential solutions.

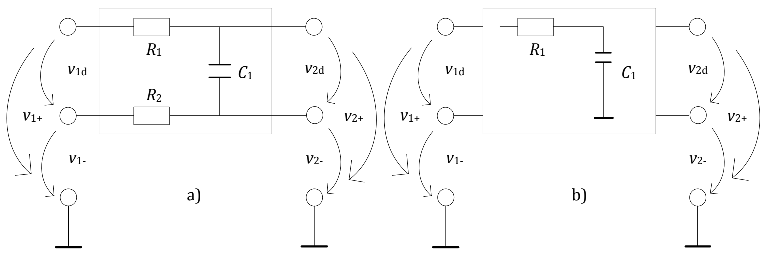

Figure 1: a) Full-differential filter, b) pseudo-differential filter

When analyzing the differential circuits operating in voltage mode, the following relations are assumed:

$$v_{1\text{d}} = v_{1+} - v_{1-}, \quad v_{2\text{d}} = v_{2+} - v_{2-}, \quad K_\text{d} = \frac{v_{2\text{d}}}{v_{1\text{d}}} = \frac{v_{2+} - v_{2-}}{v_{1+} - v_{1-}}, \tag{1a, b, c}$$

where $v_{1\text{d}}$, $v_{2\text{d}}$ and K_d denote differential input voltage, the differential output voltage and differential voltage gain, respectively. Signal $v_{1\text{d}}$ is the difference between the two input signals v_{1+} and v_{1-}. Signal $v_{2\text{d}}$ is the difference between the two output signals v_{2+} and v_{2-}. Differential voltage gain is the ratio of the differential output signal to the differential input signal.

3 DESCRIPTION OF DDCC

For the design of pseudo-differential third-order frequency filter, DDCC active element have been used. The DDCC is a six-terminal building block with three high-impedance voltage inputs Y1+, Y2- and Y3+, a low-impedance current input X, and two high-impedance current outputs Z1+ and Z1-. The relation between terminal currents and voltages is given as:

$$\begin{gathered} V_\text{x} = V_{\text{y}1+} - V_{\text{y}2-} + V_{\text{y}3+},\, I_{\text{y}1+} = I_{\text{y}2-} = I_{\text{y}3+} = 0, \\ I_{\text{z}1+} = I_\text{x},\ I_{\text{z}1-} = -I_\text{x}. \end{gathered} \tag{2a, b, c, d}$$

4 PROPOSED PSEUDO-DIFFERENTIAL THIRD-ORDER FREQUENCY FILTER OPERATING IN VOLTAGE MODE

The proposed third-order pseudo-differential frequency filter operating in voltage mode is shown in Fig. 2. is composed from four DDCCs. The structure also includes six passive elements, namely three resistors and three capacitors. The differential input signal is applied to the input terminals Y1+ and Y2- of the active element DDCC1.

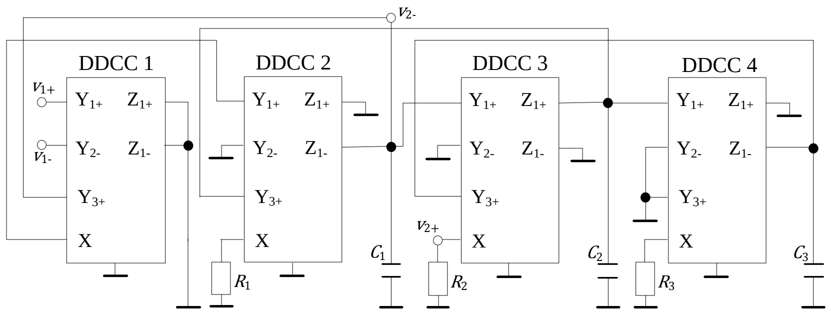

Figure 2: Pseudo-differential third-order filter operating in voltage-mode

4.1 IDEAL ANALYSIS OF THIRD-ORDER PSEUDO-DIFFERENTIAL FREQUENCY FILTER

The circuit given in Fig. 2. allows realizing one frequency filter third-order response (low-pass). Ideal analysis is described by the following equation:

$$K_\text{d} = \frac{1}{s^3 C_1 C_2 C_3 R_1 R_2 R_3 + s^2 C_2 C_3 R_2 R_3 + s(C_1 R_1 + C_3 R_3) + 1} \tag{3}$$

For simulation third-order pseudo-differential filter operating in the voltage mode, Butterworth approximation was considered. Also here, the values of capacitors $C_1 = C_2 = C_3$ =1nF were selected and the resistor values R_1 = 7962Ω, R_2= 21231Ω, R_3 = 23885Ω, were calculated resulting in 10 kHz cut-off frequency. For simulations four universal current conveyors UCC-N1B [4] was used. The plot in Fig. 5. a) show modul characteristic for low-pass filter. From the module characteristic, it is clear the low-pass filter after cut-off frequency decreases more than in the ideal case.

4.2 NON-IDEAL ANALYSIS OF THIRD-ORDER PSEUDO-DIFFERENTIAL FREQUENCY FILTER

Non-ideal analysis of active elements from the viewpoint of parasitic impedances

The performance of the filter can be affected by the parasitic impedances of the active elements. In Fig. 3, the most significant according to [4], [2] parasitics are represented by Rx, Rv, Rw, Rz, Cx, Cv, Cw, Cz, that describe the finite impedance of the Y and Z terminals of the active elements.

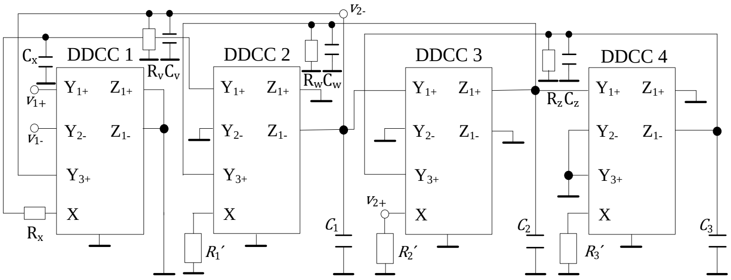

Figure 3: Pseudo-differential third-order filter with parasitic impedances

Re-analysis of the filter provides the following differential voltage gain of the low-pass filter:

$$K_d = \frac{R_vR_wR_z}{\begin{array}{l} s^4(R_1'R_2'R_3'C_1'C_2'C_3'C_xR_xR_vR_wR_z) + s^3(R_1'R_2'R_3'C_1'C_3'C_xR_xR_vR_z + R_1'R_2'R_3'C_1'C_2'C_xR_xR_vR_w + R_1'R_2'R_3'C_1'C_2' \\ C_3'C_xR_vR_wR_z + R_1'R_2'R_3'C_2'C_3'C_xR_xR_wR_z) + s^2(R_2'R_3'C_2'C_3'R_vR_wR_z + R_1'R_2'R_3'C_3'C_xR_xR_z + R_1'R_2'R_3'C_1'C_3'R_vR_z \\ +R_1'C_1'C_xR_xR_vR_wR_z + R_1'R_2'R_3'C_1'C_2'R_vR_w + R_1'R_2'R_3'C_1'R_xR_vC_x + R_3'C_3'C_xR_xR_vR_wR_z + R_1'R_2'R_3'C_2'C_xR_xR_w \\ +R_1'R_2'R_3'C_2'C_3'R_wR_z) + s(R_1'R_2'R_3'R_xC_x + R_2'C_3'R_3'R_vR_z + R_1'C_1'R_vR_wR_z + R_1'R_2'R_3'C_2'R_w + R_3'R_vR_wC_xR_x \\ +R_3'C_3'R_vR_wR_z + R_1'C_xR_xR_wR_z + R_1'C_xR_xR_wR_z + R_1'R_2'R_3'C_3'R_z + R_1'R_2'R_3'C_1'R_v + R_2'R_3'C_2'R_vR_w) + R_1'R_2'R_3' \\ +R_2'R_2'R_v + R_1'R_zR_w + R_3'R_vR_w + R_vR_wR_z \end{array}}, \tag{4}$$

where $C_1' = C_1 + C_v$, $C_2' = C_2 + C_w$, $C_3' = C_3 + C_z$, $R_1' = R_1 + R_x$, $R_2' = R_2 + R_x$, $R_3' = R_3 + R_x$,

$R_v = R_{z2} \| R_{y1} \| R_{y3}$, $R_w = R_{z1} \| R_{y1} \| R_{y3}$, $R_z = R_{z2} \| R_{y3}$, $C_v = C_{z2} + C_{y1} + C_{y3}$, $C_w = C_{z1} + C_{y1} + C_{y3}$,

$C_z = C_{z2} + C_{y3}$, $C_x = C_{y1}$, R_x, when C_x, C_z, C_y, R_x, R_z, R_y, are parasitic capacitors and resistors, respectively, wheras for sake of simplicity, the voltage and current gains of the active elements were assumed to be unity. For proper function of frequency filter it has to apply R_1; R_2; R_3 « R_v; R_w, R_z. To suppress the parasitic behavior of the active elements as much as possible, the values of passive elements should be kept as: C_1 » Cv, C_2 » Cw, C_3 » Cz and R_1, R_2, R_3 » Rx.

Non-ideal analysis of active elements from the viewpoint of the terminal relations

The performance of the filter can be affected by the terminal relations of the active elements according to [4], [2]. These relationships can be described for the DDCC as follows:

$$V_x = \alpha_1 V_{y1+} - \alpha_2 V_{y2-} + \alpha_3 V_{y3+}, I_{z1+} = \gamma_1 I_x, I_{z1-} = -\gamma_2 I_x, \tag{5a, b, c}$$

where $\alpha_m = 1 - \varepsilon_{vm}$ and $\gamma_n = 1 - \varepsilon_{in}$ (for m = {1, 2, 3} and n = {1, 2}) are the voltage and current gains of the DDCC, and $|\varepsilon_{vm}|$ « 1 and $|\varepsilon_{in}|$ « 1 denote the voltage and current tracking errors.The non-ideal voltage and current gains (5) of the active elements the differential voltage gain can be determined as:

$$K_d = \frac{s^2(C_2C_3R_2R_3\alpha_1^2\gamma_1 - C_2C_3R_2R_3\alpha_1^3\gamma_1) + \alpha_1^3\alpha_3\gamma_1^3}{s^3(C_1C_2C_3R_1R_2R_3) + s^2(C_2C_3R_2R_3\alpha_1\alpha_3\gamma_1) + s(C_3R_3\alpha_1\alpha_3\gamma_1^2 - C_1R_1\alpha_1\alpha_3\gamma_1^2) + \alpha_1^2\alpha_3^2\gamma_1^3}, \tag{6}$$

4.3 OPTIMALIZATION OF THE THIRD-ORDER PSEUDO-DIFFERENTIAL FILTER

It is evident from the non-ideal analysis of active elements in terms of parasitic impedances according to (4) parasitic impedances have not key importance on the low-pass filter. However, it cannot be said parasitic impedances analysis has no effect on the pseudo-differential filter. Taking into account the non-ideal analysis of active elements from the point of view of terminal relations according to (5), coefficients α_x and γ_x have influenced the voltage characteristic. At the low-pass filter is an undesirable error in the form of a Laplace operator s^2 together with passive elements, voltage and current gains. While ideal by (7), the member s^2 together with the passive elements and the voltage and current gains is equal to 0.

$$s^2(C_2C_3R_2R_3\alpha_1^2\gamma_1 - C_2C_3R_2R_3\alpha_1^3\gamma_1) = 0, \tag{7}$$

According to the equation (7), the condition can be defined as follows:

$$\alpha_1 = 1. \tag{8}$$

However, it is necessary to say that for this type of DDCC current conveyor according to [4], these voltage and current gains are unchanged. If there were other active element or current conveyor of similar properties that would satisfy the condition α_1 = 1 and had similar properties to [4]. We can safely say that the third-order low-pass filter would be much closer to the ideal. Optimization using the DDCC current conveyor according to [4] consists switch over terminal Y1+ with Y3+ u (DDCC 2-4) due to reduced voltage and current tracking errors because α_1 = 0.975 and α_3 = 1.009 according to [4]. For voltage terminal tracking error Y1+ - $\varepsilon_{\alpha 1}$ = 0.025 and for voltage terminal tracking error Y3+ - $\varepsilon_{\alpha 3}$ = 0.009, and also $\varepsilon_{\alpha 1} > \varepsilon_{\alpha 3}$. The DDCC 1 remained unchanged because a differential input signal is applied to terminals Y1 + and Y2-. The circuit can be seen in Fig. 4.

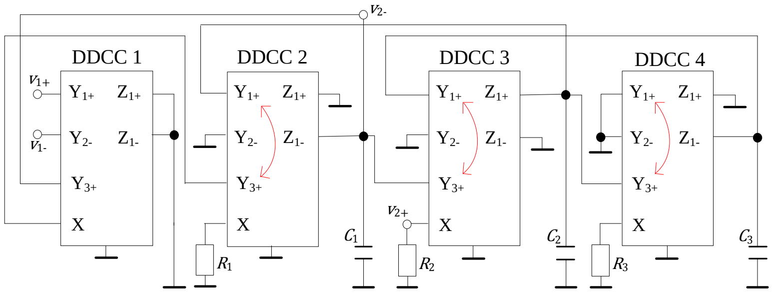

Figure 4: The optimization of Pseudo-differential third-order filter

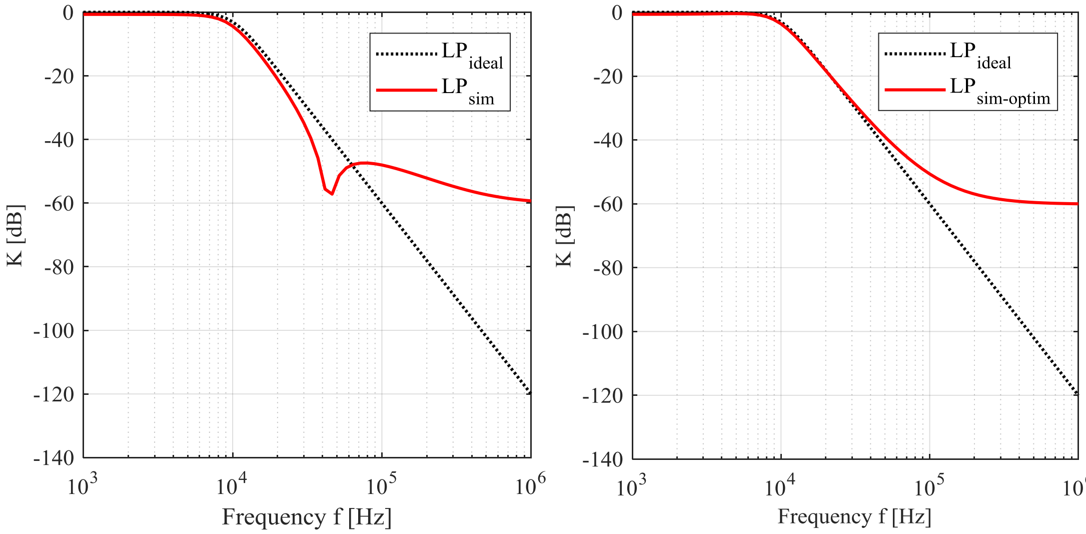

Figure 5: a) Modul of low-pass third-order filter, b) The optimization of modul of third-order low-pass filter

From the modul characteristic in Fig. 5. b) is evident that properties third-order low-pass filter improved compared to the modul characteristic in Fig. 5. a). Because the process of the modular characteristic is closer to the ideal. But if is condition fulfilled $\alpha_1 = 1$, so the modul characteristic will be closer to the ideal signal.

5 CONCLUSION

In this paper, a new pseudo-differential third-order frequency filter operating in voltage mode is presented. The proposed filter employs four differential difference current conveyor and six passive elements (three capacitors and three resistors), whereas all are grounded. The proposed structure is able to realize one standard frequency filter response (low-pass). Assuming the parasitic impedances of the active elements, the filter has not been affected. In terms of the terminal relations of the current conveyor, the condition was determined. If the condition is met, the filter will report the best properties. Filter optimization was performed by switchover Y1+ and Y3+ terminals based on better terminal properties Y3+. The lowpass filter improved after this optimization. So we can say that the technique of pseudo-differential filters can be applied to higher-order filters.

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